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Statistical Analysis of the Geologic Column Data of the Cretaceous Izumi Group, Central Japan, with Special Reference to the Sedimentation Model

By

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Abstract

Three deterministic sedimentation models are defined to analyze the geologic column data of the Upper Cretaceous Izumi Group, central Japan. Those are the constant deposition model in which all lithologies which compose the column have the same rate of sedimentation, the mixed deposion model in which a specific lithology was deposited at a constant rate while the rates of sedimentation of the other lithologies changed in the course of deposition, and the periodic deposition model in which a specific lithology was deposited periodically. According to the models, the geologic column data are transformed into serial data which can be treated as time series data. Formulations of the three models and the interrelationships among the three series are discussed.

Five columns are treated, and the chi-square test, *t* test, correlation analysis and time series analysis are adopted to examine the chosen model for the Izumi Group on the basis of information from the field. Consequently some inconsistencies are detected in one of analyzed columns, and they may be the reflection of the specific sedimentation condition.

I. Introduction

Corresponding to the increase of variety and amount of data, the data analysis has become important to extract more informations and to select only significant ones especially in the geological sciences. As an example of data analysis in geology, the geologic column data of the Izumi Group are analyzed in this paper, with special reference to the constructions of time axis for the geologic column and the sedimentation models as the basis of the time axis. The background, methods and systems of the data analysis have already been reported (YAMAMOTO and NISHIWAKI, 1975a, b; NISHIWAKI and YAMAMOTO, 1975; SAKAMAKI *et al.*, 1976).

The source data are measurements of the beds in the field, and they were transformed into a convenient form and preserved in a system file (Figure 1). The analytical process is as follows. The properties of the data were examined by calculation of the descriptive statistics, the chi-square test and the *t* test. Based on the properties the correlation analysis and the time series analysis were performed (Figure 2).

Computer programs used in this study are SPSS (NIE *et al.*, 1970, 1975; MIYAKE and YAMAMOTO, 1976), TTRE (YAMAMOTO and NAKAGAWA, 1974), and several minor ones which were developed by the author for the transformation of the data or for the connection of programs. Therefore, the explanation and the source lists of the programs are omitted. In the cource of programing the formulae in YASUDA (1969), DAVIS (1973), MORITA (1955) and MARUYAMA (1974) were used for reference.

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The calculations in this study were carried out at the Computer Centers of Kyoto University, Hokkaido University and Nagoya University.

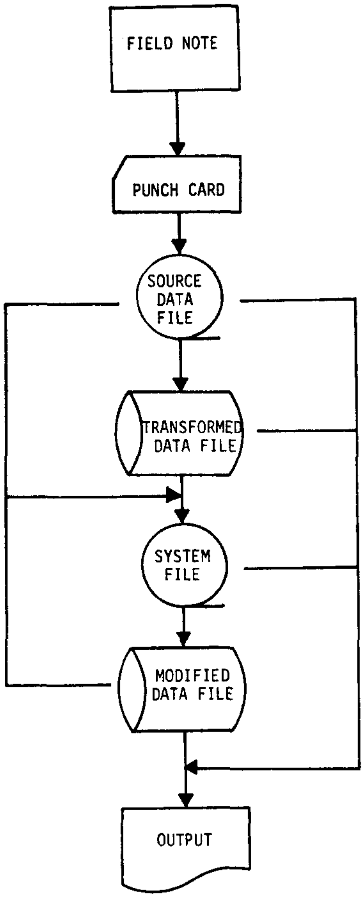


Fig. 1. Flow chart of data showing the modification process of data. The output means that the data are supplied for statistical analyses.

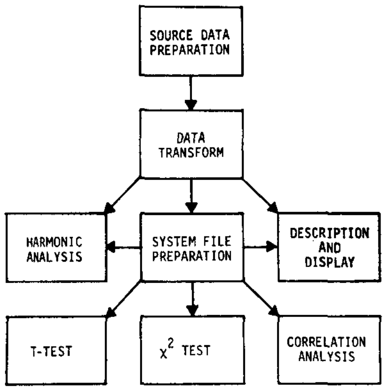


Fig. 2. Flow chart of analytical process showing that the system file is playing the central part of the analysis.

II. Sedimentation Model and Series

II.1. Time Axis of the Geologic Column

The geologic event can be expressed by using the geographic coordinates x and y, stratigraphic coordinate z and absolute time scale t. This situation is important for the reconstruction of the geologic history. The geologic column is naturally a record of geologic events in a point or an area arranged on the time axis, and can be considered as a kind of time series.

Many methods have been developed and applied in geology to treat the geologic column as time series, or at least as serieal data. The methods have been used mainly for the correlation of the strata or geologic horizons (CARRS and NEIDELL, 1966; VISTELIUS, 1961; DEAN and ANDERSON, 1967, 1974; MCCAMMON, 1966; WANLESS and WELLER, 1932). The objects of the analysis were mainly the varve (ANDERSON and KIRKLAND, 1966; ANDERSON *et al.*, 1972) or cyclic sediments (SHIELLS, 1963; WELLS, 1960), and on the latter a synthetic symposium was also held (MERRIAM, 1964). There were also other papers that tried to analyze the paleoenvironment based on the patterns of change of the geologic column (FOX and BROWN, 1965; YAMAMOTO and NAKAGAWA, 1974).

It is necessary to construct the time axis except for the geologic columns of the varve whose time axis is definite. The vertical axis of the geologic column showing the thickness of the strata was considered as a time axis in those analyses in some papers. The assumption is effective for the correlation of strata or qualitative analysis, but it is not effective for quantitative analysis. For example, there may be two geologic columns with the same length but composed of different lithologies whose rates of sedimentation are different. Then, the time length corresponding to the two geologic columns are not the same, and consequently the probabilities of some geologic event, such as submarine sliding, are different for the two geologic columns. Without considering this difference the discussion on the probability for the geologic events has no meaning.

Then it is necessary to construct the time axis for the given geologic column, and as a preceding step it is also necessary to construct the sedimentation model based on information from the field and laboratory. There are many papers on this problem with discussion of the role of potential stochastic elements (MERRIAM, 1972; SCHWARZACHER, 1976). The theme of this paper, however, is to analyze actual data, and the models discussed in the followings are only deterministic ones as a first step approximation approach.

II.2. Sedimentation Model

Generally the sedimentation should be discussed with space coordinates x, y, z, and the time coordinate t. But in the case of geologic column x and y are fixed and the sedimentation can be considered in the two-dimensional space of z and t. According to the relation of the z- and t-axes, or more concretely the choise of the t-axis, three sedimentation models were defined in which the compaction of sediments is considered to have completed.

The first model is that the z-axis is in linear relation with the t-axis, that is the relation:

$$z = c \cdot t$$

is satisfied, where c is a constant value. In this model the thickness of strata is in proportion to time, and the rate of sedimentation is constant. In this model the sedimentation can be considered only on the z- or t-axis, and the geologic column can be treated geometrically. This model is named the constant deposition model.

In the second model the t-axis is expressed by the cumulative thickness of a specific lithology. The number of lithologies which compose the geologic column is n, for example $n=2$ for the alternation of sand and mud. The rate of sedimentation of each lithology (r_i) is expressed as a function of time t:

$$r_i = g_i(t)$$

then z is expressed:

$$z = \sum_{i=1}^{n} \int_0^t g_i(t) dt$$

The function $g_i(t)$ is changeable with time in general, but in this model it is assumed to be constant for a specific i. This model means that a specific lithology has a constant rate of sedimentation. This model is named the mixed deposition model.

In the third model the t-axis is expressed by the number of occurrences of a specific event, and the number of occurrence of the event per unit time is assumed to be constant (n). The thickness of sediments deposited by the i-th event is expressed by h_i, then the formula:

$$z = \sum_{i=1}^{m} h_i$$

is satisfied, where $m = \mathrm{IFIX}(t \cdot n)$. IFIX means a maximum integer which never exceeds the value in the parentheses. This model requires the presence of markers which indicate the time interval in the geologic column. This model is named the periodic deposition model.

Examples of these models for the alternation of sand and mud is given in Figures 3a–c, and the change of thickness in time is shown in Figures 4a–c.

Of course it is possible to assume other sedimentation models for the geologic column, and further, those which can explain two or three dimensional change of sediments should also be considered. In this paper only the three deterministic models mentioned above are discussed as a first step, for the author could not collect the data to explain such comprehensive models under limited condition of the outcrops.

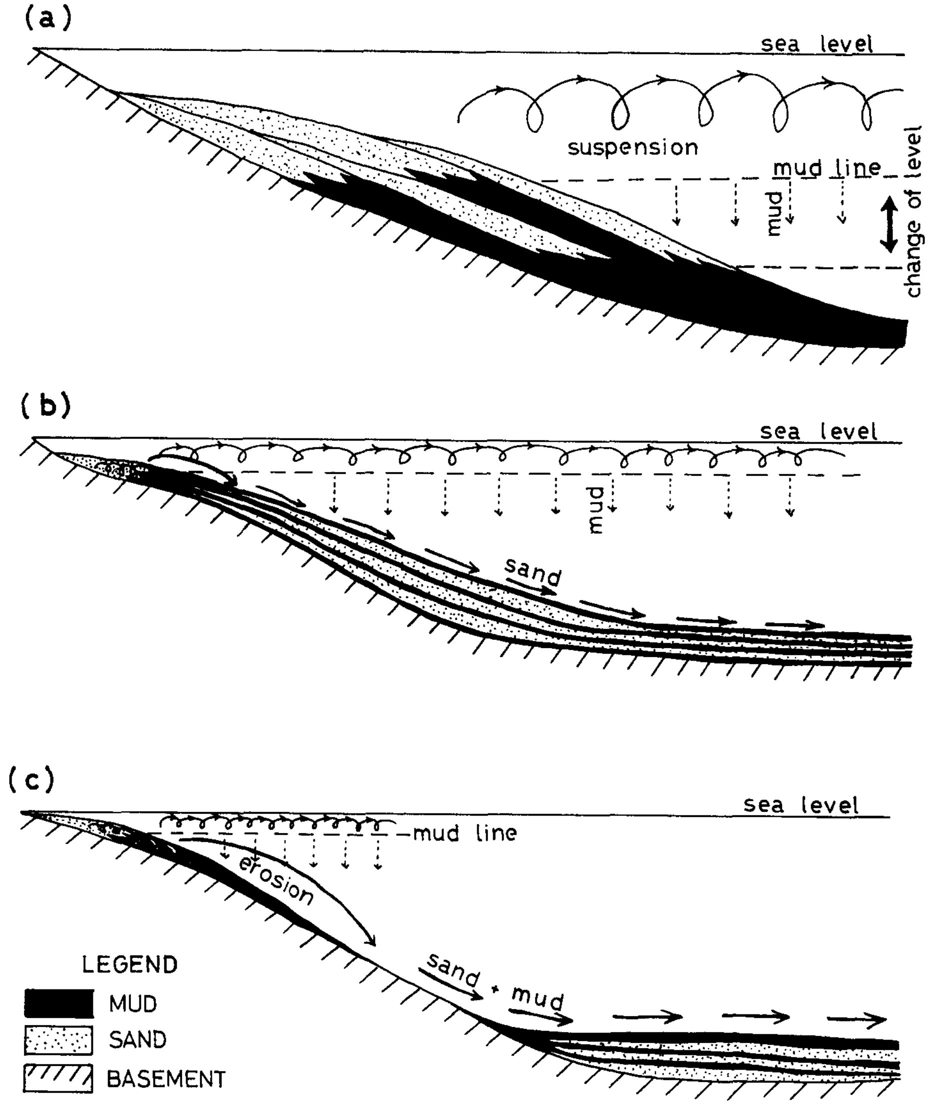


Fig. 3. Examples of the three sedimentation models for the alternation of sand and mud. (a) constant deposition model which is caused by the fluctuation of the sea level, (b) mixed deposition model in which the mud is transported by suspension while a sand layer is transported by a turbidity current, (c) periodic deposition model in which a pair of sand and mud layers is transported by a turbidity current.

II.3. Transformation into Series

The geologic column is a set of geologic records and is merely data as it stands.

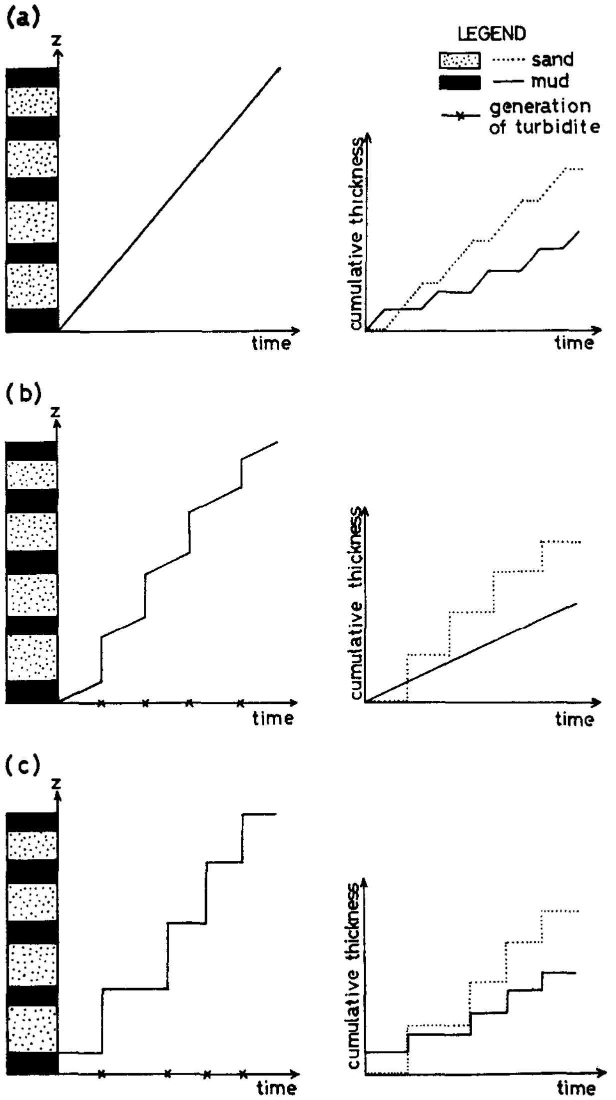


Fig. 4. Changes of deposited sediments in the three sedimentation models which are shown in Fig. 3. (a) constant deposition model, (b) mixed deposition model, (c) periodic deposition model.

To treat the geologic column as serial data, it is necessary to define the vertical axis. Since the general geologic column is composed of many lithologies whose rates of sedimentation and geological meanings are different from one another, the definition of the vertical axis is not easy. But it is rather easy to reconstruct the geologic events on the time axis based on the sedimentation models mentioned already.

In this paper the geologic column composed of two lithologies was treated as a foundation for the study of geologic columns composed of multiple lithologies. The

Table 1. Formulae of the basic variables calculated in the three series. Detail explanation of the codes of variables are given in Table 3.

SEDIMENTATION MODEL		CONSTANT DEPOSITION MODEL	MIXED DEPOSITION MODEL	PERIODIC DEPOSITIOM MODEL
SERIES		DISTANCE SERIES (X-SERIES)	THICKNESS SERIES (V-SERIES)	NUMBER SERIES (N-SERIES)
SANDSTONE	NUMBER	X2 = ns	V2 = ns	Cn
	TOTAL THICKNESS	ts	V3 = ts	ts
	MEAN THICKNESS	$X4 = \frac{ts}{X2}$	$V4 = \frac{V3}{V2}$	$N4 = \frac{ts}{Cn}$
	RATIO	$X3 = \frac{ts}{Cx}$	$\frac{V3}{Cv + V3}$	$N3 = \frac{100 \cdot N4}{N4 + N5}$
SHALE	NUMBER	-	-	Cn
	TOTAL THICKNESS	Cx - ts	Cv	th
	MEAN THICKNESS	-	-	$N5 = \frac{th}{Cn}$
	RATIO	1 - X3	$\frac{Cv}{Cv + V3}$	$1 - \frac{N3}{100}$
GRADED BED	MEAN THICKNESS	-	-	N6 = ts + th
COLUMN SLICE	TOTAL THICKNESS	Cx	Cv + V3	Cn·N6

Cx,Cv,Cn: constant value, ns,ts,th: measured value, -: not considered.

alternation of sand and mud is transformed into the series as a most general example of the two lithologies case (Table 1, Figure 5).

From the view point of the constant deposition model, the sand and mud are considered to have an equal rate of sedimentation. The geologic column is cut into column slices of the same length, each of which corresponds to a term or case in the later analysis, and for each of the column slice records of the geologic events are collected and the mean values of them are calculated. In this model the actual process does not rearrange the data, but defines the vertical axis of the geologic column as a time axis. The defined series is based on the distance from the top of the column, and is named the distance series (Dr. Adam SYNOWIEC, 1975, private communication) and coded the *X*-series.

From the view point of the mixed deposition model, sand or mud is considered to have a constant rate of sedimentation. It is generally accepted that the mud

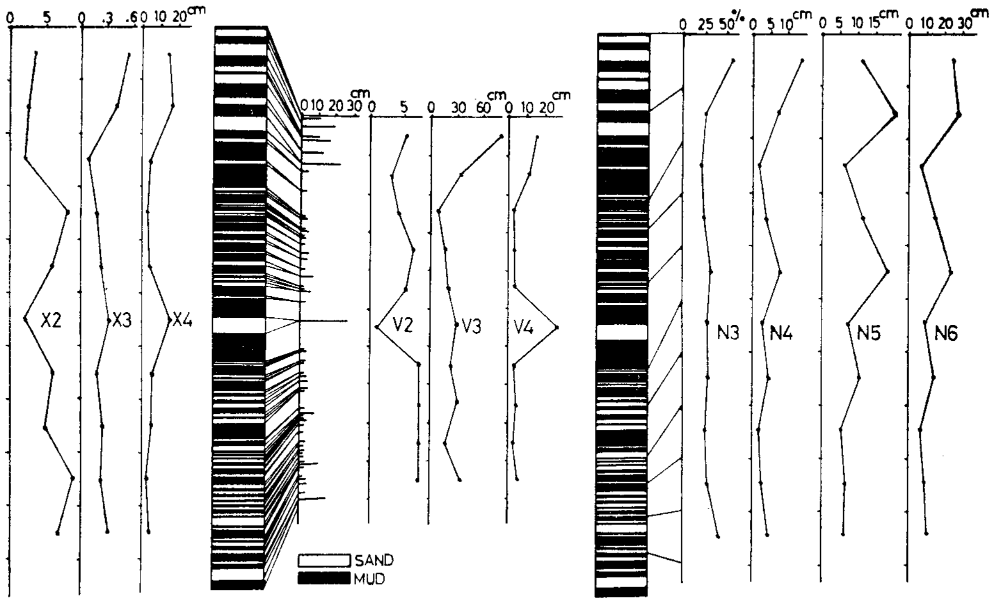


Fig. 5. Example showing the interrelationship among the three series. The two columns are the same. The pillar graph just right of the left column shows the thickness of sandstone. Other codes are the same as those in Table 3.

deposited constantly and the sand deposited intermittently for this type of alternation, so the cumulative thickness of mud is considered as the basis of cutting the geologic column into column slices, each of which corresponds to a term or case in the later analysis. The geologic events are collected for the column slice whose cumulative thickness of mud is constant. This series is based on the thickness of mud, and is named the thickness series and coded the *V*-series.

From the view point of the periodic deposition model, the base of sand is considered as a marker, that is, a graded bed is defined from the base of sand to the top of the mud overlying the sand. The deposition of the graded bed is assumed to proceed with a constant time interval and the number of the graded bed is considered as a basis of cutting the geologic column into column slices, each of which corresponds to a term or case in the later analysis. The geologic events are collected for the column slice which has a constant number of graded bed. This series is based on the number of bed, and is named the number series and coded the *N*-series. The position that the graded beds were deposited with a constant time interval is based on the two assumptions. The one is that a graded bed is corresponds to a event which occures only rately, and the other is that the time interval of events is constant. Of course the latter assumption is not true in the strict sense because the Poisson process should be expected for such events (SCHWARZACHER, 1975), but it is not unreasonable from the macroscopic point of view.

The formulae of the variables calculated in each series are given in Table 1, and the more detailed definition of them is in Table 3.

The three series are arranged on the time axis, and the methods of the time series analysis can be applied to them. But the time axis in the three series are defined based on the sedimentation models, and the direct relations with the actual time axis are not clear, so they are not called time series but by other series names in the present paper.

II.4. Interrelationship among Series

The three series mentioned above are based on the sedimentation models different from one another, and it is impossible to define direct relations among them. The distance series is the series transformed based on the constant deposition model on the one hand, and it is a geometric expression of the geologic column on the other hand. From the view point of the latter, the simulated column, based on the mixed or periodic deposition model as the basis for the thickness or number series, can be transformed into the distance series. In the same way the simulated column based on the periodic deposition model can be transformed into the thickness series. In the course of the formulation of these transformation, the relations among the three series can be examined.

The formulation of the three series and the discussion of the relations among them are in the followings (Figures 6a–b).

First the sedimentation is assumed to process according to the mixed deposition model. $\boldsymbol{r}$ is the rate of sedimentation of mud, and it is constant. $\boldsymbol{d}$ is the cumulative thickness of column at time $\boldsymbol{t}$, $\boldsymbol{n}$ is the number of sand layer deposited for a unit time, $\boldsymbol{a}$ is the thickness of a sand layer. Then $\boldsymbol{a}\cdot\boldsymbol{n}$ is the rate of sedimentation of sand, and $\boldsymbol{d}$ is expressed:

$$\boldsymbol{d}=\boldsymbol{r}\cdot\boldsymbol{t}+\int_0^{\boldsymbol{t}}\boldsymbol{a}\cdot\boldsymbol{n}\,\mathrm{d}\boldsymbol{t}$$

The thickness of a sand layer and the number of sand layer per unit time vary with time, then $\boldsymbol{a}$ and $\boldsymbol{n}$ are expressed as the functions of time $\boldsymbol{t}$:

$$\boldsymbol{a}=\boldsymbol{g}(\boldsymbol{t})$$

$$\boldsymbol{n}=\boldsymbol{f}(\boldsymbol{t})$$

then $\boldsymbol{d}$ is expressed:

$$\boldsymbol{d}=\boldsymbol{r}\cdot\boldsymbol{t}+\int_0^{\boldsymbol{t}}\boldsymbol{f}(\boldsymbol{t})\cdot\boldsymbol{g}(\boldsymbol{t})\,\mathrm{d}\boldsymbol{t}$$

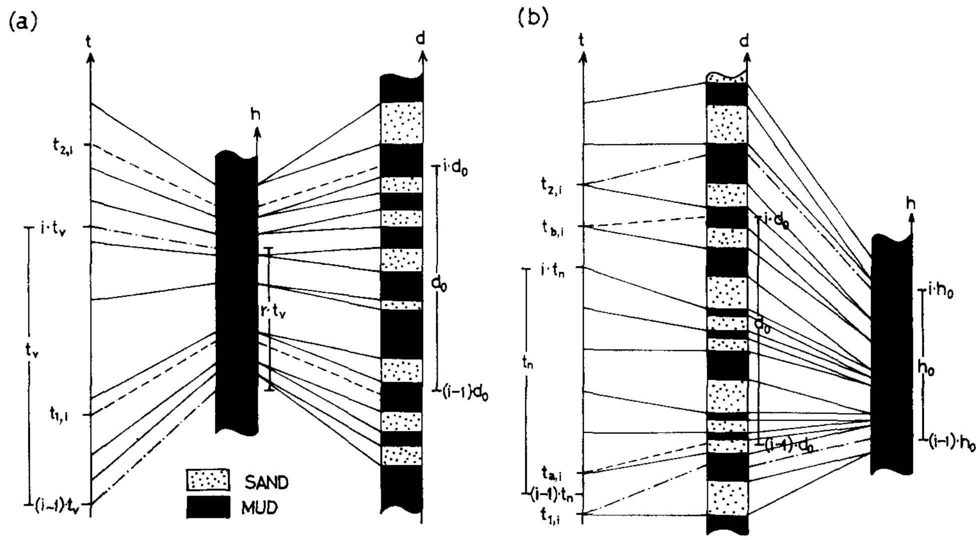


Fig. 6. Explanations of column slices used in the simulation. (a) based on the mixed deposition model, (b) based on the periodic deposition model. Other codes are the same as those in the text.

The i-th column slice in this mixed deposition model or thickness series is deposited in the time interval from $(i-1) \cdot t_v$ to $i \cdot t_v$ and the variables for the column slice are defined as follows.

number of sand layer: $V2_i = \int_{(i-1) \cdot t_v}^{i \cdot t_v} f(t)\, dt$

total thickness of sand: $V3_i = \int_{(i-1) \cdot t_v}^{i \cdot t_v} f(t) \cdot g(t)\, dt$

mean thickness of sand layer: $V4_i = \dfrac{V3_i}{V2_i}$

where t_v is the time length corresponding to the column slice in the thickness series and it is constant, in other word, $r \cdot t_v$ is the cumulative thickness of mud of a column slice.

The i-th column slice in the distance series, which is transformed from the simulated column, is defined to be deposited in the time interval from $t_{1,i}$ to $t_{2,i}$ which satisfy:

$$(i-1) \cdot d_0 = r \cdot t_{1,i} + \int_0^{t_{1,i}} f(t) \cdot g(t)\, dt$$

$$i \cdot d_0 = r \cdot t_{2,i} + \int_0^{t_{2,i}} f(t) \cdot g(t)\, dt$$

where d_0 is the length of a column slice in the distance series and it is constant. Then the variables for the i-th column slice in the distance series are defined as follows.

number of sand layer: $X2_i = \int_{t_{1,i}}^{t_{2,i}} f(t)\ \mathrm{d}t$

sand ratio: $X3_i = \frac{1}{d_0}\int_{t_{1,i}}^{t_{2,i}} f(t)\cdot g(t)\ \mathrm{d}t$

mean thickness of sand layer: $X4_i = \frac{d_0 \cdot X3_i}{X2_i}$

Next the sedimentation is assumed to process according to the periodic deposition model. n is the number of the graded bed deposited in a unit time and is constant. b is the thickness of a mud layer. Then $(a+b)$ is the thickness of a graded bed, and d is the cumulative thickness of column and expressed:

$$d = \int_0^t (a+b)\cdot n\ \mathrm{d}t$$

a and b are expressed as the functions of time t:

$$a = g(t)$$

$$b = h(t)$$

then d is expressed:

$$d = \int_0^t \{g(t) + h(t)\}\cdot n\ \mathrm{d}t$$

Let designate the time length as t_n corresponding to the length of a column slice in the number series and is constant. Then the column slice in the periodic deposition model or the number series is deposited in the time interval from $(i-1)\cdot t_n$ to $i\cdot t_n$ and the variables for the column slice in the number series are defined as follows.

mean thickness of sand layer: $N4_i = \frac{1}{t_n \cdot n}\int_{(i-1)\cdot t_n}^{i\cdot t_n} g(t)\cdot n\ \mathrm{d}t$

mean thickness of mud layer: $N5_i = \frac{1}{t_n \cdot n}\int_{(i-1)\cdot t_n}^{i\cdot t_n} h(t)\cdot n\ \mathrm{d}t$

mean thickness of graded bed: $N6_i = N4_i + N5_i$

sand ratio: $N3_i = \frac{100\cdot N4_i}{N6_i}$

Similarly the i-th column slice in the distance series, which is transformed from the simulated column, is defined to be deposited in the time interval from $t_{a,i}$ to $t_{b,i}$ which satisfy:

$$(i-1)\cdot d_0=\int_0^{t_{a,i}}\{g(t)+h(t)\}\cdot n\,dt$$

$$i\cdot d_0=\int_0^{t_{b,i}}\{g(t)+h(t)\}\cdot n\,dt$$

The variables for the i-th column slice in the distance series are defined as follows.

number of sand layer: $X2_i=\dfrac{(t_{b,i}-t_{a,i})\cdot n}{t_n}$

sand ratio: $X3_i=\dfrac{\int_{t_{a,i}}^{t_{b,i}}g(t)\cdot n\,dt}{\int_{t_{a,i}}^{t_{b,i}}\{g(t)+h(t)\}\cdot n\,dt}$

mean thickness of sand layer: $X4_i=\dfrac{d_0\cdot X3_i}{X2_i}$

If we misunderstand this column simulated according to the periodic deposition model, and transform it into the thickness series based on the mixed deposition model. h_0 is the cumulative thickness of mud of the column slice in the thickness series and is assumed to be constant. The i-th column slice in the thickness series is deposited in the time interval from $t_{1,i}$ to $t_{2,i}$ which satisfy:

$$(i-1)\cdot h_0=\int_0^{t_{1,i}}h(t)\cdot n\,dt$$

$$i\cdot h_0=\int_0^{t_{2,i}}h(t)\cdot n\,dt$$

The variables for the column slice in the thickness series are defined as follows.

number of sand layer: $V2_i=\dfrac{(t_{2,i}-t_{1,i})\cdot n}{t_n}$

total thickness of sand: $V3_i=\int_{t_{1,i}}^{t_{2,i}}g(t)\cdot n\,dt$

mean thickness of sand layer: $V4_i=\dfrac{V3_i}{V2_i}$

By using the definition formulae mentioned above, and setting some functions for $f(t)$, $g(t)$ and $h(t)$, the geologic column could be generated by the computer simulation. The results are shown in Figures 7a-b, and the functions used are in Tables 2a–b.

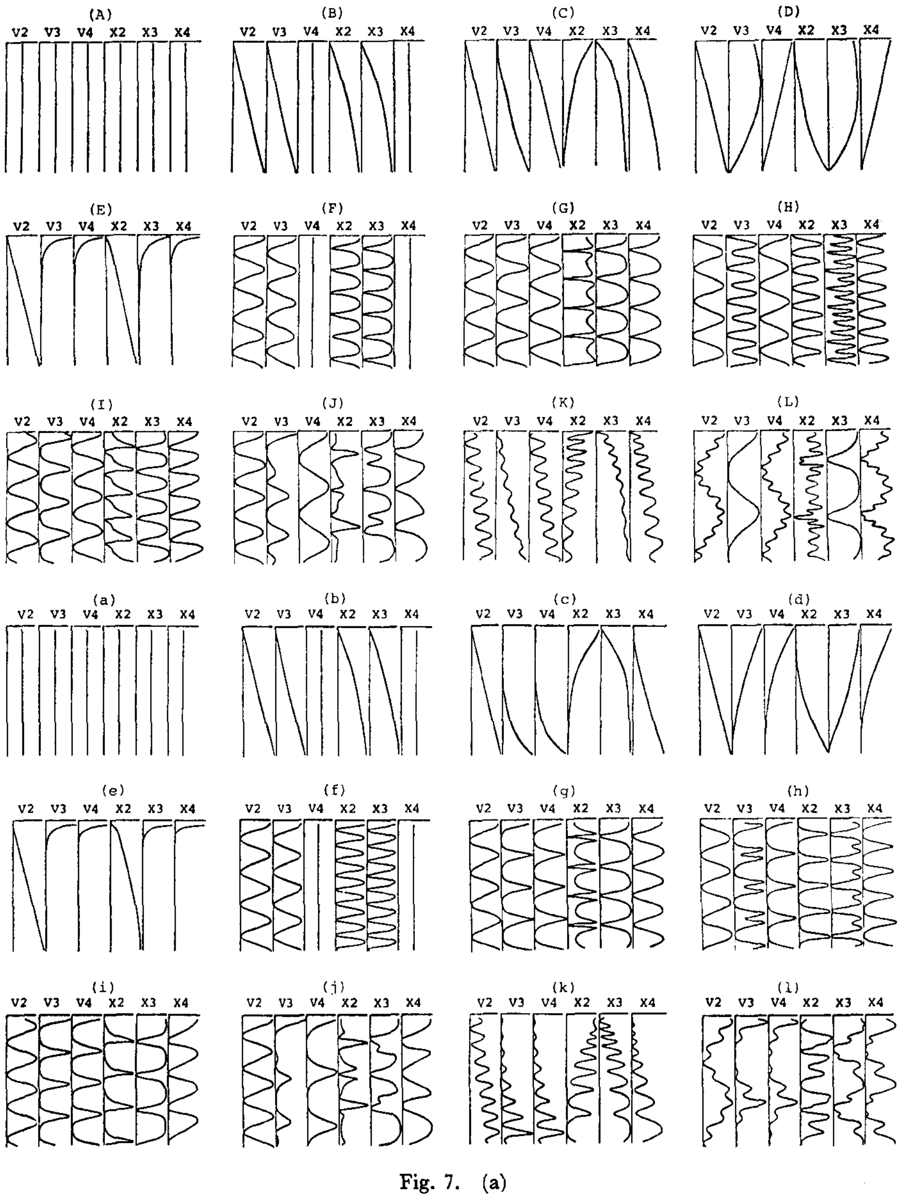


Fig. 7. (a)

Fig. 7. Display of each variable in the generated column by the simulation. (a) according to the mixed deposition model, (b) according to the periodic deposition model. Functions used in the simulation are in Table 2. Computation was done for 50 terms, and one term is defined with 300 cm total thickness in the distance series, 100 cm cumulative thickness of mud in the thickness series, or 10 beds in the number series, though in several cases other definition is used to avoid errors in computation.

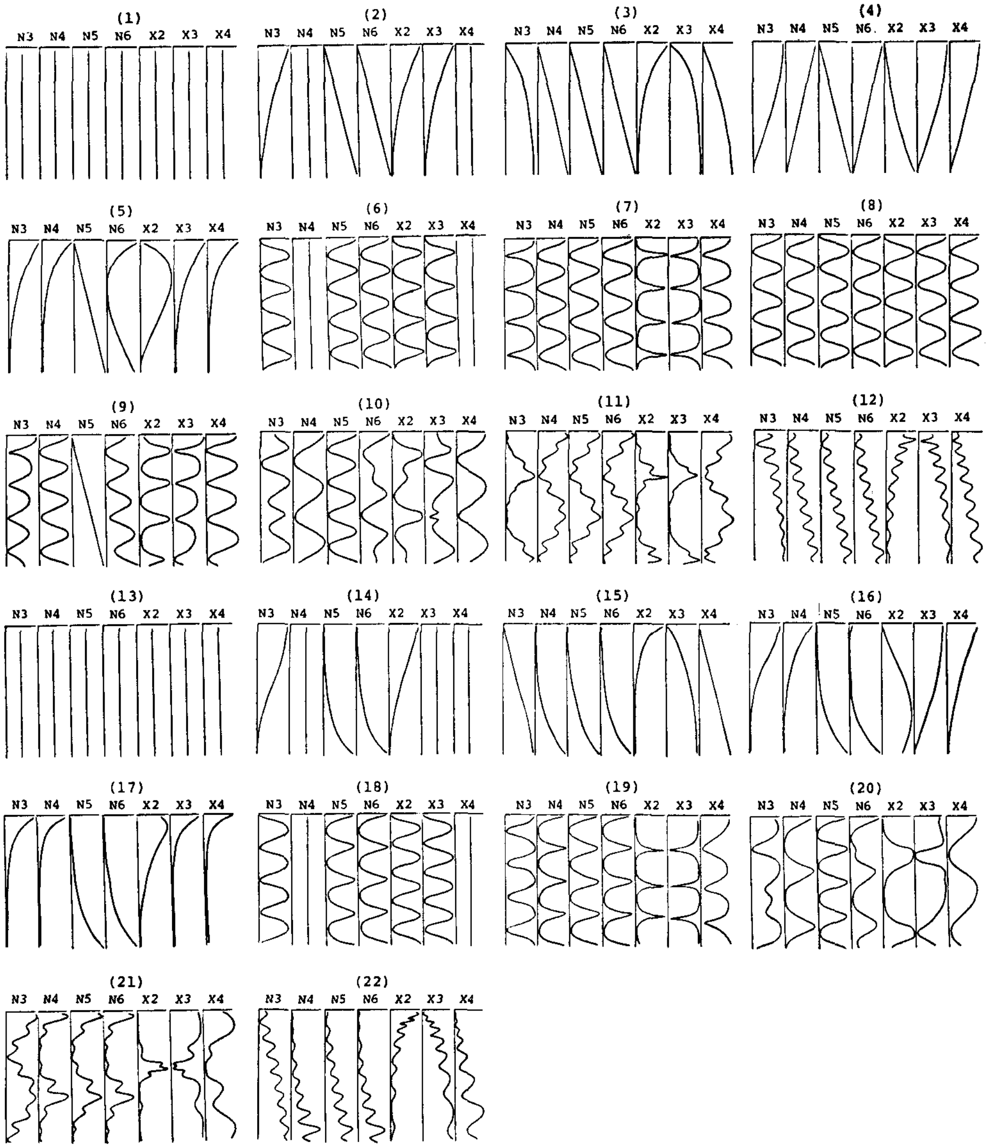


Fig. 7. (b)

The important cases are as follows. In the case **C** and **c** where both the number and thickness of sand layer increases with time, the number of sand layer decreases with time in the generated column. In cases **J** and **j** where the periods of the cyclicity of the number and thickness of sand layer are different from one another, the

Table 2. Functions used in the simulation to generate the geologic columns. (a) according for the number of sand layer per unit time, $g(t)$: function for the thickness of a

(a)

CASE	$f(t)$	$g(t)$
A	0.1	20
B	$0.05+0.00001t$	20
C	$0.05+0.00001t$	$10+0.01t$
D	$0.05+0.00001t$	$40-0.005t$
E	$0.05+0.00001t$	$500/(t+100)$
F	$0.051+0.05\cos(0.005t)$	20
G	$0.051+0.05\cos(0.005t)$	$22+20\cos(0.005t)$
H	$0.051+0.05\cos(0.005t+3.14159)$	$22+20\cos(0.005t)$
I	$0.051+0.05\sin(0.005t)$	$22+20\cos(0.005t)$
J	$0.051+0.05\cos(0.005t)$	$22+20\cos(0.003t)$
K	$0.05+0.00001t+0.02\sin(0.01t)$	$10+0.005t-10\cos(0.01t)$
L	$0.07+0.05\cos(0.002t)+0.02\sin(0.015t)$	$13+9\cos(0.002t)-4\cos(0.015t)$
a	0.1	e^{2}
b	$0.05+0.00001t$	e^{2}
c	$0.05+0.00001t$	$e^{(1+0.001t)}$
d	$0.05+0.00001t$	$e^{(4-0.0005t)}$
e	$0.05+0.00001t$	$e^{(500/(t+100))}$
f	$0.051+0.05\cos(0.005t)$	e^{2}
g	$0.051+0.05\cos(0.005t)$	$e^{2(1.1+\cos(0.005t))}$
h	$0.051+0.05\cos(0.005t+3.14159)$	$e^{3(1.1+\cos(0.005t))}$
i	$0.051+0.05\cos(0.005t)$	$e^{2.4(1.1+\cos(0.005t))}$
j	$0.051+0.05\cos(0.005t)$	$e^{2(1.1+\cos(2+0.002t))}$
k	$0.05+0.00001t+0.02\sin(0.01t)$	$e^{(1+0.0005t+\sin(0.01t))}$
l	$0.07+0.05\cos(0.002t)+0.02\sin(0.01t)$	$e^{(1.95+1.35\cos(0.002t)+0.6\sin(0.01t))}$

number of sand layer shows the random pattern of change in the generated column. In cases **K** and **k** where the number of sand layer per unit time show a cyclic change, the period changes with time in the generated column.

Similar patterns are shown in the columns generated according to the periodic deposition model in the cases **3**, **15**, **10**, **20**, **12** and **22**.

The result of the simulation indicates that the wrong selection of the sedimentation model leads to wrong understanding of the pattern of the original change.

II.5. Application of Sedimentation Model

The sedimentation model as the foundation of analysis of the geologic column should be selected essentially based on information from the field and laboratory. Of course it is necessary to reject the model if some inconsistencies become obvious to the mixed deposition model, (b) according to the periodic deposition model. $\boldsymbol{f}(\boldsymbol{t})$: function sand layer, $\boldsymbol{h}(\boldsymbol{t})$: function for the thickness of a mud layer.

(b)

CASE	$g(t)$	$h(t)$
1	0.2	0.1
2	0.2	$0.05+0.000003t$
3	$0.09+0.000005t$	$0.1+0.000003t$
4	$0.3-0.000005t$	$0.05+0.000003t$
5	$2000/(t+10000)$	$0.1+0.000003t$
6	0.2	$0.1+0.08 \cos(0.0005t)$
7	$0.2+0.15 \cos(0.0005t)$	$0.1+0.06 \cos(0.0005t)$
8	$0.2+0.1 \cos(0.0005t)$	$0.1-0.07 \cos(0.0005t)$
9	$0.2+0.15 \cos(0.0005t)$	$0.05+0.000003t$
10	$0.2+0.1 \cos(0.0003t)$	$0.1+0.08 \cos(0.0005t)$
11	$0.2+0.09 \cos(0.0002t)+0.04 \sin(0.001t)$	$0.1+0.05 \cos(0.0002t)+0.02 \sin(0.001t)$
12	$0.08+0.000004t+0.04 \sin(0.001t)$	$0.07+0.000002t+0.02 \sin(0.001t)$
13	$0.01\, e^{3}$	$0.01\, e$
14	$0.01\, e^{3}$	$0.01\, e^{1.25+0.000075t}$
15	$0.01\, e^{1.35+0.000075t}$	$0.01\, e^{1.5+0.000045t}$
16	$0.01\, e^{4.5-0.000075t}$	$0.01\, e^{2.5+0.000075t}$
17	$0.01\, e^{30000/(t+10000)}$	$0.01\, e^{2.5+0.000075t}$
18	$0.01\, e^{3}$	$0.01\, e^{1.5+1.2 \cos(0.0005t)}$
19	$0.01\, e^{3+2.25 \cos(0.0005t)}$	$0.01\, e^{1.5+0.9 \cos(0.0005t)}$
20	$0.01\, e^{3+1.5 \cos(0.0003t)}$	$0.01\, e^{1.5+1.2 \cos(0.0005t)}$
21	$0.01\, e^{3+1.45 \cos(0.0002t)+0.6 \sin(0.001t)}$	$0.01\, e^{1.5+0.75 \cos(0.0002t)+0.3 \sin(0.001t)}$
22	$0.01\, e^{1.2+0.00006t+0.6 \sin(0.001t)}$	$0.01\, e^{1.05+0.00003t+0.6 \sin(0.001t)}$

in the course of analysis using the model, and it is also possible to search the proper model for the geologic column in the trial and error with the help of well-equipped systems for the data analysis.

Types of sediments to which the three models mentioned above can be applicable are as follows.

The constant deposition model, where the length of geologic column is considered the time axis, is applicable to the sediments composed of a uniform lithology, or at least of combination of lithologies whose rates of sedimentation are within a limited range. It is also necessary that the compaction of sediments can be neglected. The ooze in the open ocean floor and fine-grained lake sediments under the stable environments are possible examples of such sediments. The permitted range of the rate of sedimentation is decided by the reciprocal relation between the accuracy of the data and the purpose of the analysis.

The mixed deposition model, where the thickness of a certain lithology is considered the time axis, is applicable to the sediments that one of several lithologies can be considered to have deposited at a constant rate of sedimentation, or at least more constant rate than the others. It is also necessary that the compaction of sediments can be neglected. The sediments which is composed mainly of the normal offshore sediments intercalated by coarse-grained sediments supplied by the storms, and those which is composed of pelagic sediments intercalated by turbidite layers are examples of such sediments. That is, this model is applicable when two or more kinds of sedimentation mechanisms are in effect simultaneously, and one of them causes the deposition of a constant rate of sedimentation.

The periodic deposition model, where the number of some lithology or record of some geologic events is considered as the time axis, is applicable to the sediments which have records of events periodic, or at least to be considered more periodic than the other events. The varve, each of whose layers corresponds to a year, is the best example and has been analyzed by many researchers. The annual ring of wood which is used in the analysis of the paleoclimatic change is another example.

The models mentioned in this paper are only simple ones and the applications of them are limited. Of course, they have fairly wide applications when the purpose of the analysis permits large range of error. The application can be expanded by transforming from the multiple lithologies to the two lithologies, or by admitting the periodicity in the macroscopic point of view.

Other models should be considered to explain not only the data of the geologic column, but also the data which have two or three dimentional change of lithology or records of geologic events. After achieving such comprehensive models it become possible to clarify the sedimentation mechanism, and to contribute in constructing the geologic history.

III. Analysis of the Izumi Group

III.1. Geology and Data

III.1.a. Geology

Data analyzed in this study are observed and measured by the author in the field on the Izumi Group in the southwestern part of the Awaji Island, central Japan.

There are many reports on the Izumi Group; the stratigraphy is discussed by NAKANO (1953), NAKAGAWA (1961), SUYARI (1966, 1973), and so on, the paleontology by YABE (1915), ICHIKAWA and MAEDA (1958a, b, 1960), and so on, and the sedimentology by TANAKA (1965), SUYARI *et al.* (1968), and so on. These results are summarized as follows.

The Izumi Group is the Upper Cretaceous sediments distributed in a narrow zone called the Izumi Belt of about 300 km length in E-W direction and of about 30 km width in N-S direction. The area studied in this paper is located a little east of the center of the zone. The Izumi Group has a large basinal structure whose axis plunges to east. The age of the sediments becomes younger in the east than in the west. Apparent total thickness of the Izumi Group reaches 100,000 m, but only about 8,000 m can be observed in the studied area because of the structure mentioned above. The lithology of the Izumi Group is mainly composed of alternation of sandstone and shale except for the basal conglomerate observed along the northern boundary of the Izumi Belt. Only small amount of conglomerates and acidic tuffs are intercalated in the alternation. Lateral and vertical changes of lithology in the alternation are so remarkable that the division of the strata is difficult. Two kinds of lithofacies, that is, sandstone-rich and shale-rich, are repeated each about 2,000 m thick. The repetition of the lithofacies is used for the key of the stratigraphic subdivision, and the Izumi Group in the studied area is divided into seven formations by using the key (SASAI, 1936; NISHIWAKI, 1974MS). Because of such criterion of the subdivision, the interfingering relations among formations are proved in the course of the field survey (Figure 8).

GEOLOGIC AGE		STRATIGRAPHIC SUBDIVISION		THICKNESS
PLEISTOCENE		TERRACE DEPOSITS		5 m
PLIOCENE		AWAJI GROUP		150 m
LATE CRETACEOUS	HETONAIAN ~ URAKAWAN	IZUMI GROUP	KITAAMA SANDSTONE FORMATION	1500 m
			FUKURA SHALE FORMATION	700 m
			TOZAKI SANDSTONE FORMATION	1500 m
			SHICHI SHALE FORMATION	400 m
			YOROIZAKI SANDSTONE FORMATION	1500 m
			MINATO SHALE FORMATION	350 m
			TSUI CONGLOMERATE FORMATION	250 m
	GYLIAKIAN	SENNAN ACIDIC ROCKS		?

Fig. 8. Stratigraphic subdivision of the southwestern part of the Awaji Island, central Japan. The thickness of the shale formations decreases to the west, and the sandstone formations show the reverse trend.

The sandstone layer of the Izumi Group has a sharp boundary on both of the top and base, and has no clear internal structures which are characteristic of turbidite. The sandstones of this group, however, is considered to have been deposited by the turbidity currents in a wide sense, since the sole marking and the graded bedding structure are well observed in the sandstone. It is obvious from the paleocurrent direction, the composition of clastic materials and other evidences, that the sandstones were supplied from east to west, and the source area of the sandstone was in the north of the basin. The characteristics mentioned above are common almost all over the Izumi Belt.

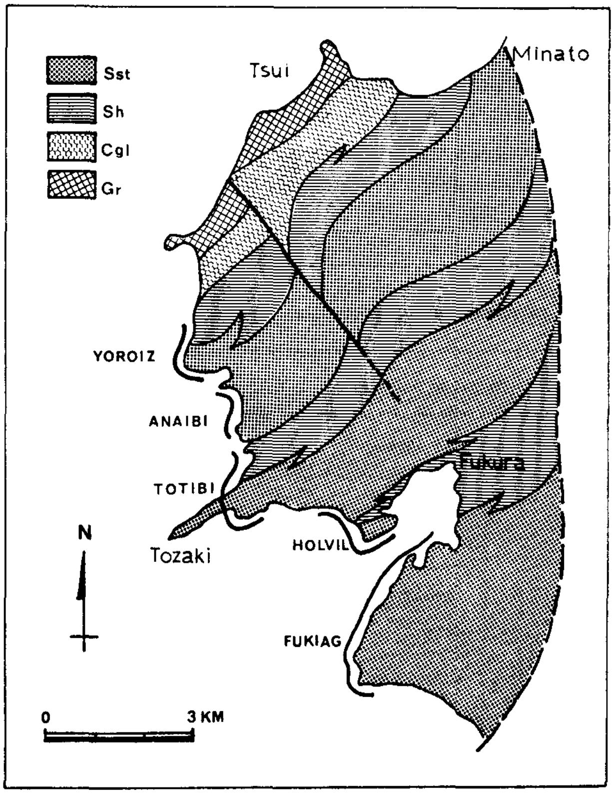


Fig. 9. Generalized geologic map of the southwestern part of the Awaji Island showing the measurement localities of the analyzed columns. Gr: Sennan Acidic Rocks, Cgl: Tsui Conglomerate Formation, Sh: Minato, Shichi, and Fukura Shale Formations, Sst: Yoroizaki, Tozaki and Kitaama Sandstone Formations.

III.1.b. Collection of Data

Only the northern half of the basinal structure of the Izumi Group is observed in the studied area (Figure 9). Although many minute faults and minute folds are observed, younger formations generally crop out in the southern area. The outcrop of the continuous section for the geologic column analysis are limited in the coastal area. The data used in this study were collected only from this area. It is impossible to compare the geologic columns in the lateral direction.

In the field the thickness of each bed was measured in centimeter unit, the lithology of the bed and the sedimentary structures observed in the bed were described, and fossils and other characteristics were recorded. The number of measured beds is more than

25,000, even though only 45% of total thickness of the Izumi Group in this area is covered. In the following analyses mainly five columns are used which are not complete but well continuous. The whole column, the TTREDATA column, is also used but only for reference.

III.1.c. Transformation into Series

Based on the information from the field mentioned above, the constant deposition model is to be rejected for the Izumi Group. It is also obvious that the periodic deposition model is not suitable since the boundary of the sandstone with the overlying shale is too sharp to regard a set of sandstone and shale as one graded bed.

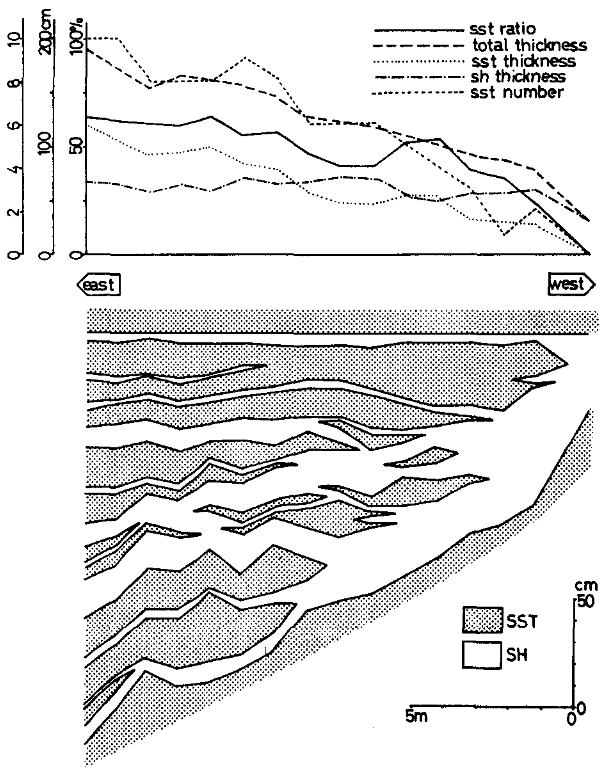


Fig. 10. Lateral change of lithology observed in the Tozaki Sandstone Formation in the beach cliff, south of Ibi, Nandan Town, Awaji Island. The upper one shows the changes of the sandstone ratio, total thickness, cumulative thickness of sandstone and that of shale between the two sandstones on the top and base. The lower one shows the sketch whose vertical scale is enlarged.

Furthermore there is a field evidence to determine the sedimentation model of the Izumi Group. It is a lateral change of lithology in the Tozaki Sandstone Formation (Figure 10). The sandstones are thinning out from east to west between the two continuous sandstone beds on the top and base of the observed outcrop. In contrast with the change of the thickness of the sandstone, the total thickness of shale between the two continuous sandstone beds is stable. This strongly suggests the mixed deposition model, that is, the shale had deposited continuously while the sandstones had deposited intermittently (NISHIWAKI, 1975).

Therefore it seems to be suitable to transform the geologic columns into the thickness series (*V*-series). In this paper, however, the comparisons among the

Table 3. Code and explanation of variables used in this study. The definitions in this table are used unless otherwise mentioned.

X2:	number of sandstone bed in a column slice whose thickness is 500 cm (FUKIAG, HOLVIL, TOTIBI, ANAIBI and YOROIZ) or 50 m (TTREDATA)
X3:	sandstone ratio in a column slice mentioned above
X4:	mean thickness of sandstone bed in a column slice mentioned above (cm)
V2:	number of sandstone bed in a column slice, cumulated thickness of shale in the column is 200 cm (FUKIAG, HOLVIL, TOTIBI, ANAIBI, and YOROIZ) or 20 m (TTREDATA)
V3:	total thickness of sandstone in a column slice mentioned above (cm)
V4:	mean thickness of sandstone bed in a column slice mentioned above (cm)
N3:	sandstone ratio in a column slice, number of sandstone bed in the column is 16 (FUKIAG, HOLVIL, TOTIBI, ANAIBI, and YOROIZ) or 100 (TTREDATA) (%)
N4:	mean thickness of sandstone bed in a column slice mentioned above (cm)
N5:	mean thickness of shale bed in a column slice mentioned above (cm)
N6:	sum of mean thickness of sandstone bed and shale bed in a column slice mentioned above (cm)
T2, T3, T4, R2, R3, R4, L3, L4, L5, L6:	logarithm of X2, X3, X4, V2, V3, V4, N3, N4, N5, N6, if necessary some corrections were done to avoid computational error
NUMSOLE:	number of sole marking in a column slice mentioned above
HGTSOLE:	mean height of sole marking in a column slice mentioned above (cm)
CURRENT:	mean direction of paleocurrent in a column slice mentioned above (degree measured clockwise from north)
FL:	number of flute-type current marking, that is, those showing the orientation, in a column slice mentioned above
GR:	number of groove type current marking, that is, those showing direction only, in a column slice mentioned above
THKSLUMP:	total thickness of slumped zone in a column slice mentioned above (cm)
NUMSLUMP:	number of slumped zone in a column slice mentioned above
THKTUFF:	total thickness of slumped zone in a column slice mentioned above (cm)
NUMTUFF:	number of tuffaceous layer in a column slice mentioned above
LEBEN:	number of bed, in which fossils including trace fossils were observed, in a column slice mentioned above
MDSS:	number of muddy sandstone and muddy conglomerate in a column slice mentioned above
THKCGL:	total thickness of conglomerate in a column slice mentioned above (cm)
NUMCGL:	number of conglomerate bed in a column slice mentioned above
SEQNUM:	sequence number of column slice from top of the column, and it is one of system variables automatically generated by the SPSS system when the system file is created. 200·SEQNUM means cumulated thickness of shale from the top of column in the *V*-series (cm), and 500·SEQNUM means depth from the top of column in the *X*-series (cm)

series are discussed to examine the application for the field data, and the geologic columns were transformed into the three series stated already.

III.1.d. Explanation of Variable

In this paper the variables were expressed by using the codes shown in Table 3, and the codes were used in the text unless otherwise cited, not only for the convenience at computer analysis, but also to avoid the troublesomeness of repeating the explanations. In the interpretation of the analyzed result the meaning of the variables cannot be neglected, and the discussion was done by using the original meanings of the variables, not with the codes.

Among five columns, the HOLVIL column exhibits a best section because the data were obtained in a good exposure, and the definition of a column slice in each series is determined such as that the number of term of the HOLVIL column becomes almost same with each series.

Considering the thickness and the sedimentation time of the whole Izumi Group, a column slice which corresponds to a term or case in each series is considered to be deposited during about 2,000 years. It is a fairly long time and the errors of measurement and effects of cutting into column slices could be considered to be disappeared.

III.1.e. Descriptive Statistics and Display

Five of six columns used in this study are shown in Table 4 and their localities are shown in Figure 9. One more column, the TTREDATA column, is compiled from the five columns by estimating the data for the lacking parts of the outcrops. Excepting the time series analysis and several of the correlation analysis the five columns are treated as a whole, and it is not same with the TTREDATA column because the estimated data are not included in this treatment.

The relations among three series are shown in Figures 11a–c. Not the straight line but the curved and/or turned line is obtained for each case, and it means that the series is different from each other. The relations between the distance series and the number series for the TTREDATA column is expressed by fairly straight line, and the two series are considered to be similar in the macroscopic point of view. It may be explained by the fact that the Izumi Group has a uniform lithology, that is, it is composed mainly of the alternation of sandstone and shale in which the thickness of bed is fairly constant.

The descriptive statistics are given in Tables 5a–c. The statistics for the same kind of variable in each series has not the same value with each other, and it means that the transformation into the series plays an important role.

Table 4. Description of columns analyzed in this study. The term corresponds 200 cm thickness of cumulative shale in the thickness series, or 16 beds Those for the TTREDATA column are 50 m length of column, 20 m

COLUMN	FORMATION	LOCALITY	NUMBER OF MEASUREMENT
FUKIAG	Kitaama Sst	Ikami - Fukiage	2226
HOLVIL	Tozaki Sst	Holiday village	4944
TOTIBI	Shichi Sh - Tozaki Sst	Ibi - Tottori	2663
ANAIBI	Yoroizaki Sst	Anaga - Ibi	4029
YOROIZ	Anaga Sh - Yoroizaki Sst	Anaga	2637
TTREDATA	Tsui Cgl - Kitaama Sst	Maruyama - Fukiage	17483

Table 5. Descriptive statistics of each variable used in this study.

X-SERIES (a)

VARIABLE NAME	MEAN	STANDARD DEVIATION	KURTOSIS	SKEWNESS	MINIMUM	MAXIMUM	VALID OBSERVATION
X2	16.449	10.311	0.774	0.873	0.0	57.0	570
X3	0.573	0.265	-0.483	-0.537	0.0	1.0	570
X4	23.595	32.520	87.691	7.417	0.0	500.0	570
NUMSOLE	2.931	2.667	5.206	2.129	1.0	16.0	232
HGTSOLE	2.247	1.930	16.381	3.318	0.5	15.0	232
CURRENT	105.051	41.452	0.067	0.173	7.0	245.0	118
FL	1.393	0.792	5.231	2.260	1.0	5.0	84
GR	1.235	0.586	9.212	2.930	1.0	4.0	51
THKSLUMP	107.451	96.118	3.176	1.662	7.0	500.0	122
NUMSLUMP	1.361	0.814	18.326	3.597	1.0	7.0	122
THKTUFF	227.667	364.370	2.206	1.930	8.0	1190.0	21
NUMTUFF	5.667	7.165	2.136	1.815	1.0	27.0	21
LEBEN	2.027	1.581	5.713	2.270	1.0	9.0	73
MDSS	1.631	0.958	2.342	1.645	1.0	5.0	130
THKCGL	50.024	50.974	3.965	1.937	1.0	261.0	124
NUMCGL	1.847	1.162	1.715	1.456	1.0	6.0	124
T2	2.636	0.765	2.142	-1.278	0.0	4.060	570
T3	5.367	1.133	9.320	-2.949	0.0	6.217	570
T4	2.787	0.922	1.128	-0.332	0.0	6.217	570

The actual data are displayed in Figures 12a–e. They are the output of all data in the system file, and the 11-term running averaged values are also displayed for the number and thickness of sandstone, the sandstone ratio, and the thickness of shale.

It is obvious that the cases with missing values are very frequent, that is, many items were not observed for many cases. There is a strong effect of the random process. The difference among the three series is not very significant, but it becomes clear in the course of analysis.

to a column slice which is defined with 500cm length of column in the distance series, of sandstone in the number series, for the columns from FUKIAG to YOROIZ. thickness of cumulative shale, and 100 beds of sandstone respectively.

COLUMN LENGTH	THICKNESS OF SHALE	NUMBER OF SANDSTONE	NUMBER OF TERM X-SERIES	V-SERIES	N-SERIES
m	m				
349.69	145.82	1194	69	72	74
814.29	327.44	2628	162	163	164
780.14	428.32	1601	156	214	100
599.03	214.21	2380	119	107	148
324.54	185.55	1468	64	92	91
5792.52	3057.82	14627	115	152	146

(a) distance series, (b) thickness series, (c) number series.

V-SERIES (b)

VARIABLE NAME	MEAN	STANDARD DEVIATION	KURTOSIS	SKEWNESS	MINIMUM	MAXIMUM	VALID OBSERVATION
V2	14.313	10.393	0.158	0.680	1.0	55.0	648
V3	238.370	312.858	7.884	2.558	0.0	2100.0	648
V4	15.003	17.255	8.954	2.630	0.0	129.0	648
NUMSOLE	3.378	3.312	5.517	2.211	1.0	19.0	201
HGTSOLE	2.094	1.570	22.966	3.660	0.5	15.0	201
CURRENT	104.155	38.894	-0.470	0.064	14.0	195.0	97
FL	1.568	1.111	7.634	2.602	1.0	7.0	74
GR	1.348	0.766	9.821	2.918	1.0	5.0	46
THKSLUMP	109.116	91.826	2.638	1.483	7.0	500.0	121
NUMSLUMP	1.413	0.738	5.471	2.176	1.0	5.0	121
THKTUFF	238.800	372.400	1.827	1.837	2.0	1190.0	20
NUMTUFF	6.000	7.413	1.492	1.624	1.0	27.0	20
LEBEN	2.056	1.698	9.769	2.716	1.0	11.0	71
MDSS	1.571	0.915	3.820	1.841	1.0	6.0	133
THKCGL	49.270	70.622	26.658	4.483	2.0	567.0	111
NUMCGL	1.964	1.794	11.992	3.169	1.0	12.0	111
R2	2.409	0.905	-0.596	-0.720	0.693	4.025	648
R3	4.423	1.911	0.251	-1.001	0.0	7.650	648
R4	2.279	1.066	-0.079	-0.393	0.0	4.870	648

III.2. Chi-Square Test

III.2.a. Purpose and Method

In the statistical analysis of the observed data, the type of analysis applicable to the data is restricted by the pattern of the frequency distribution of the observed values. For example, in the calculation of the correlation coefficient the normal distribution is expected for each of the paired variables. The normality of the observed data should be examined before the multivariate analysis which is based on the correlation coefficient matrix.

Table 5. (continued)

N-SERIES (c)

VARIABLE NAME	MEAN	STANDARD DEVIATION	KURTOSIS	SKEWNESS	MINIMUM	MAXIMUM	VALID OBSERVATION
N3	53.547	21.257	-0.686	-0.113	1.481	97.119	577
N4	16.690	14.953	5.742	2.027	1.125	108.125	577
N5	13.158	19.072	88.803	8.462	1.063	257.750	577
N6	29.848	24.518	29.705	4.345	29.705	261.625	577
NUMSOLE	2.987	2.501	2.023	1.565	1.0	12.0	231
HGTSOLE	2.140	1.574	6.249	2.163	0.5	10.5	231
CURRENT	100.884	38.643	-0.467	-0.102	4.0	182.0	112
FL	1.429	0.765	2.036	1.725	1.0	4.0	84
GR	1.220	0.582	10.379	3.156	1.0	4.0	50
THKSLUMP	104.736	100.233	5.407	2.099	7.0	575.0	121
NUMSLUMP	1.331	0.688	8.811	2.731	1.0	5.0	121
THKTUFF	236.789	333.355	1.677	1.724	8.0	1148.0	19
NUMTUFF	6.737	7.218	1.700	1.649	1.0	27.0	19
LEBEN	1.915	1.547	3.221	2.036	1.0	7.0	71
MDSS	1.565	0.869	3.389	1.825	1.0	5.0	131
THKCGL	48.713	58.591	6.567	2.400	1.0	338.0	122
NUMCGL	1.893	1.359	2.104	1.634	1.0	7.0	122
L3	3.869	0.542	6.492	-1.934	0.393	4.576	577
L4	2.460	0.864	-0.629	-0.047	0.118	4.683	577
L5	2.288	0.651	3.218	0.972	0.061	5.552	577
L6	3.196	0.600	0.419	0.494	1.958	5.567	577

The chi-square is calculated to examine the normality of the frequency distribution of the data. The formula is:

$$\chi^2 = \sum_{i=1}^{n} \frac{(x_{i,e} - x_{i,o})^2}{x_{i,e}}$$

where n is the number of class, $x_{i,o}$ is the observed frequency of the i-th class, and $x_{i,e}$ is the expected frequency which is calculated from the normal distribution whose number of data, mean and variance are same with those of the observed data. The degree of freedom Df is:

$$Df = n - 3$$

The frequency distribution of the bed thickness is generally considered to be normal in the logarithmic scale (KIMURA, 1966; BOKMAN, 1952, 1957; SIMPSON, 1970). The values of the chi-square in the both of the linear and logarithmic scales were calculated for the actual frequency distribution of the bed thickness of each lithology. The chi-square was calculated on the frequency distribution of the values of each variable used in each series to examine the normality of the variables which were used for the calculation of the statistical values in the later analyses.

Fig. 11. Relation among the series. (a) relation between the distance and thickness series, (b) relation between the distance and number series, (c) relation between the thickness and number series. (1) TTREDATA column, (2) FUKIAG, HOLVIL, TOTIBI, ANAIBI and YOROIZ columns.

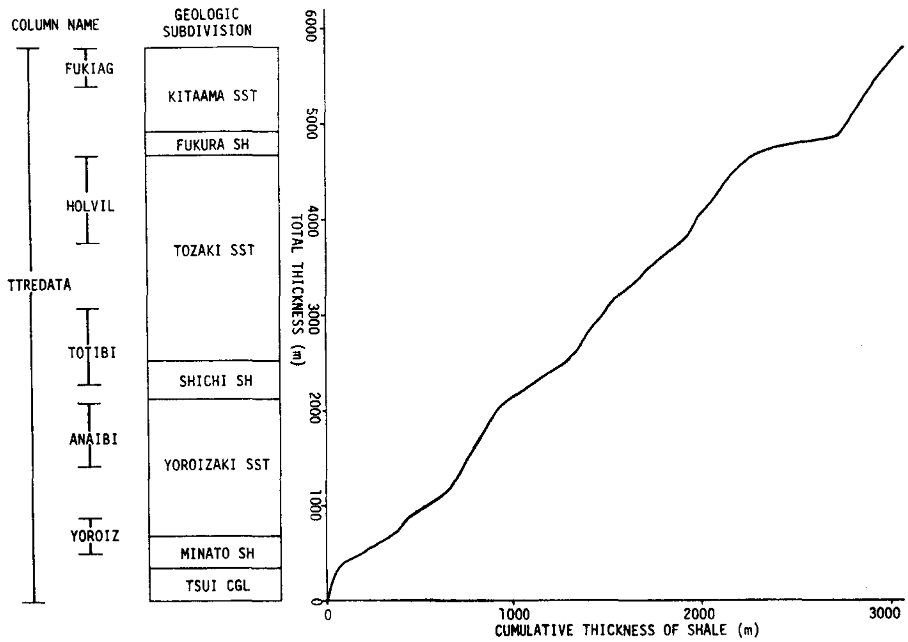


Fig. 11. (a–1)

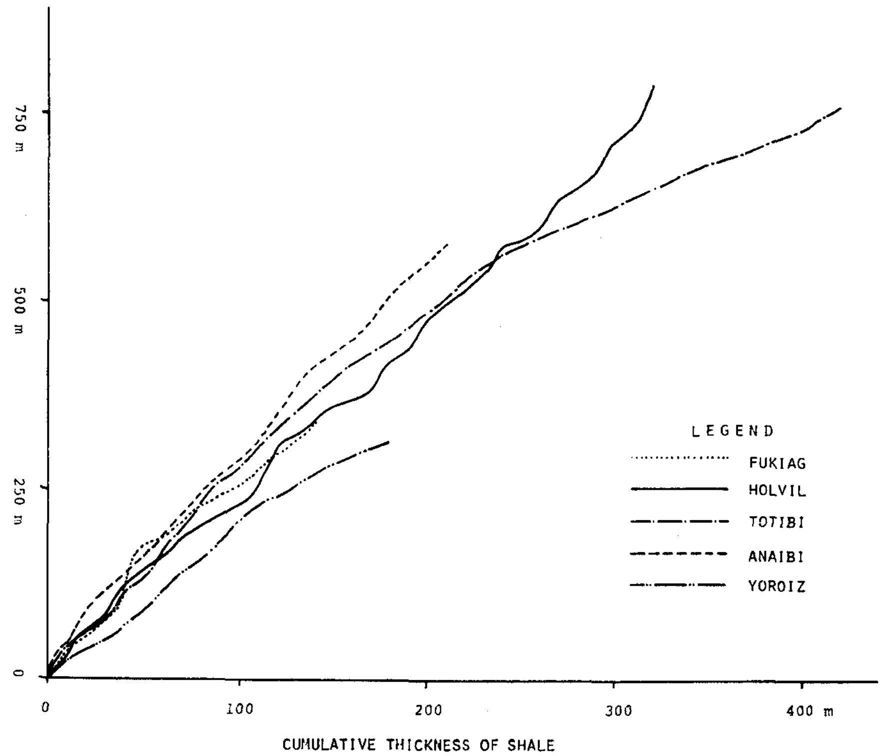


Fig. 11. (a–2)

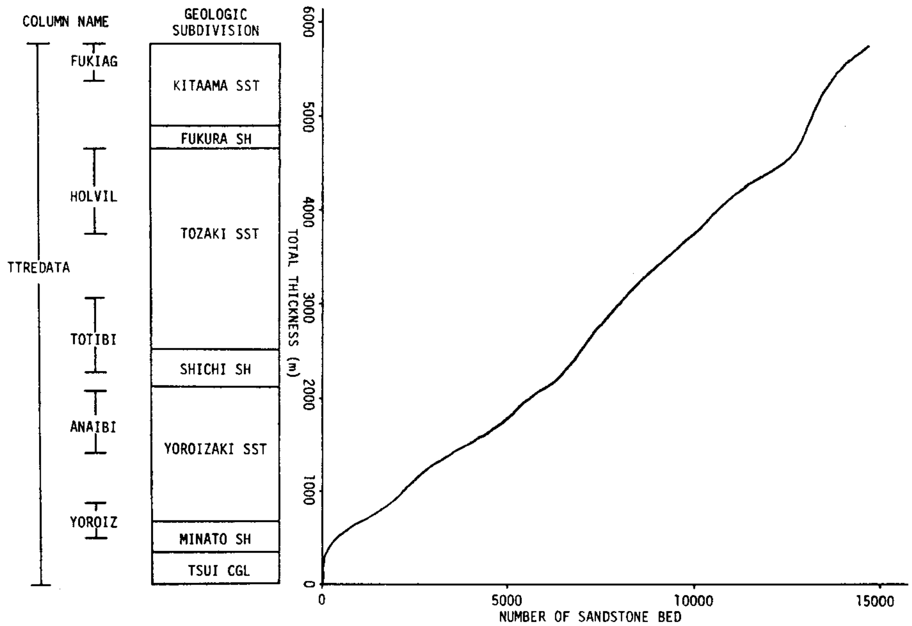


Fig. 11. (b–1)

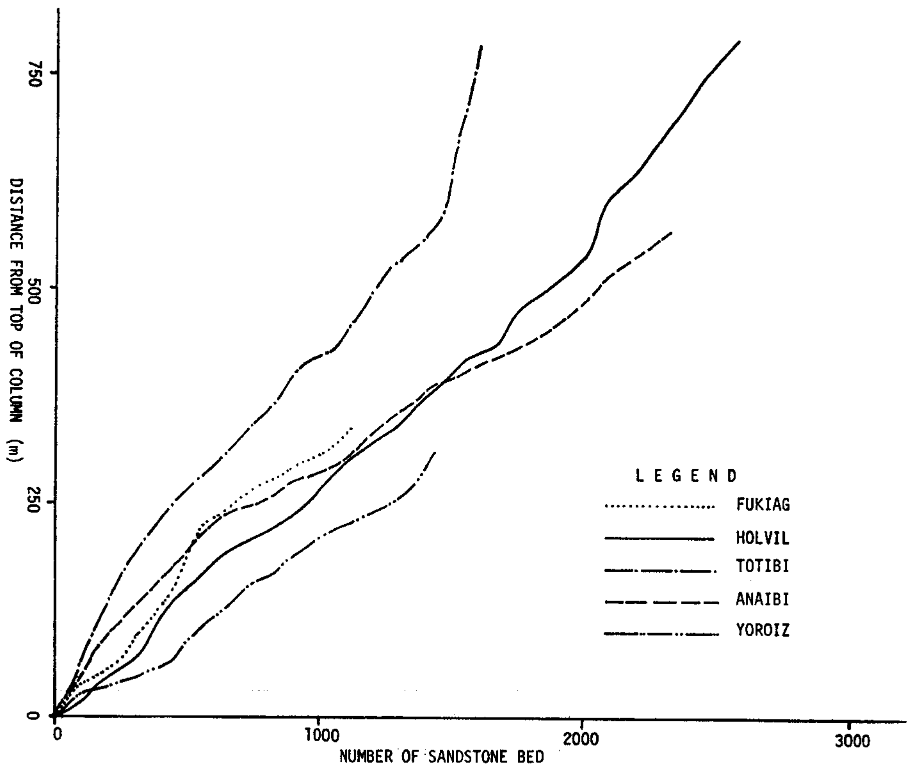


Fig. 11. (b–2)

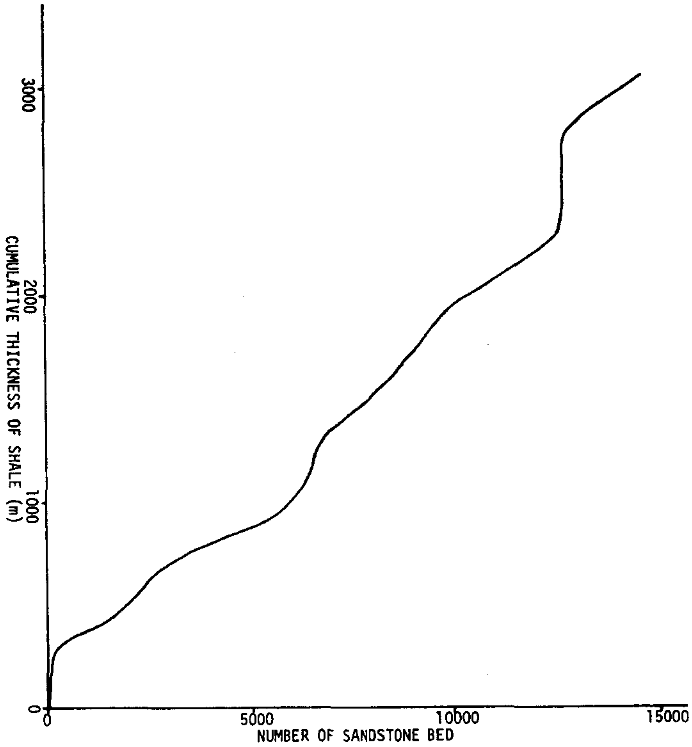


Fig. 11. (c–1)

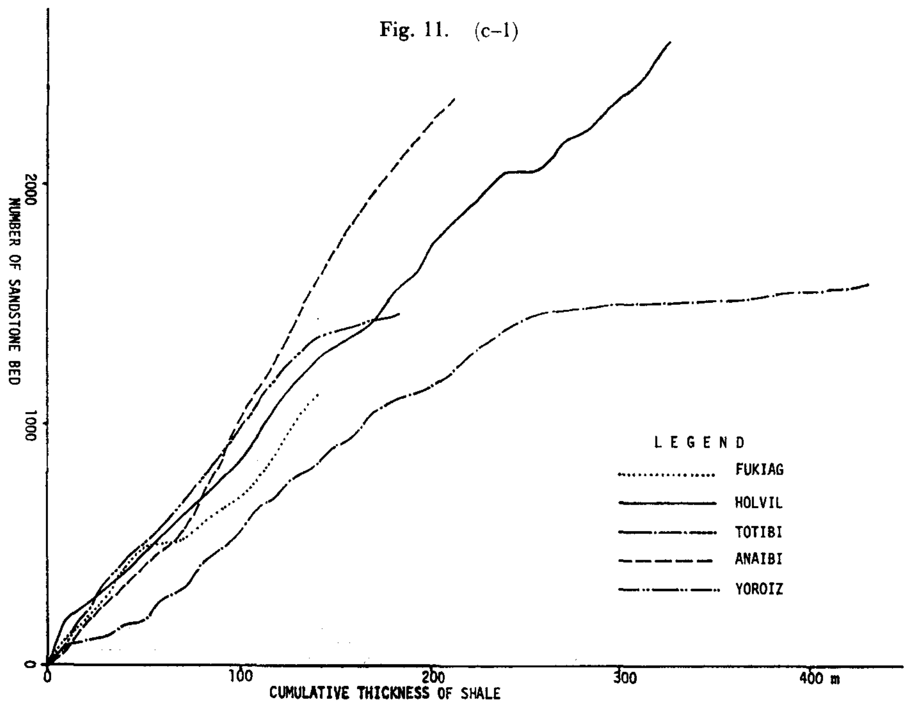


Fig. 11. (c–2)

Fig. 12. (a–x)

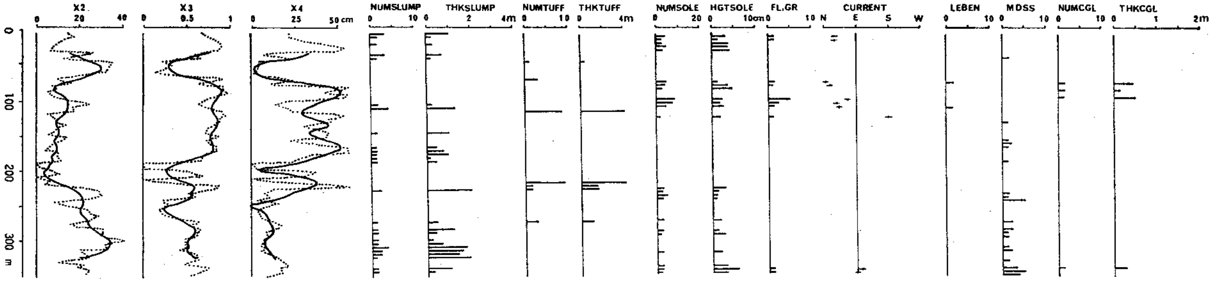


Fig. 12. (a–v)

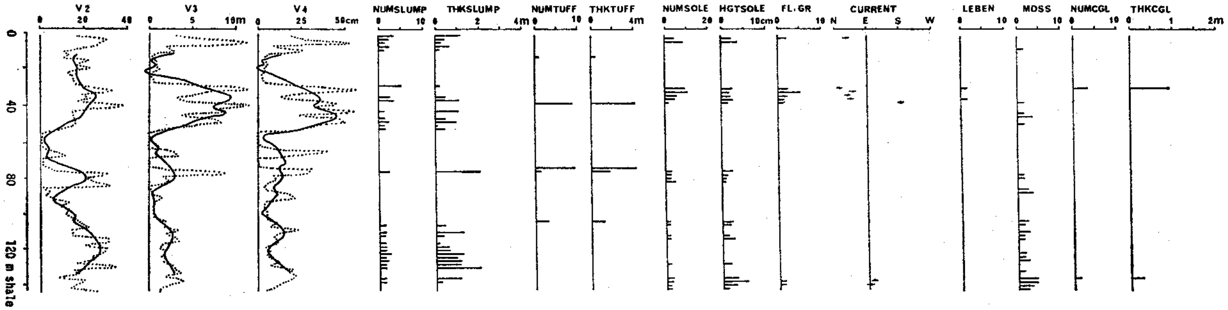


Fig. 12. (a–N)

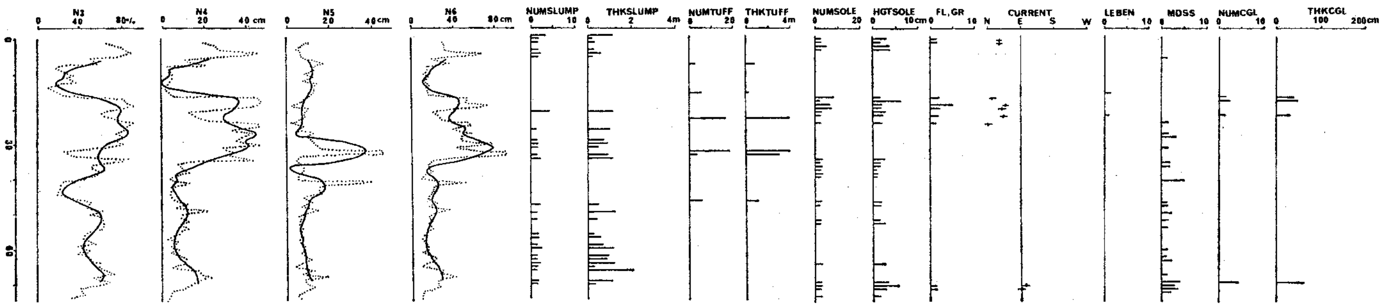


Fig. 12. (b–x)

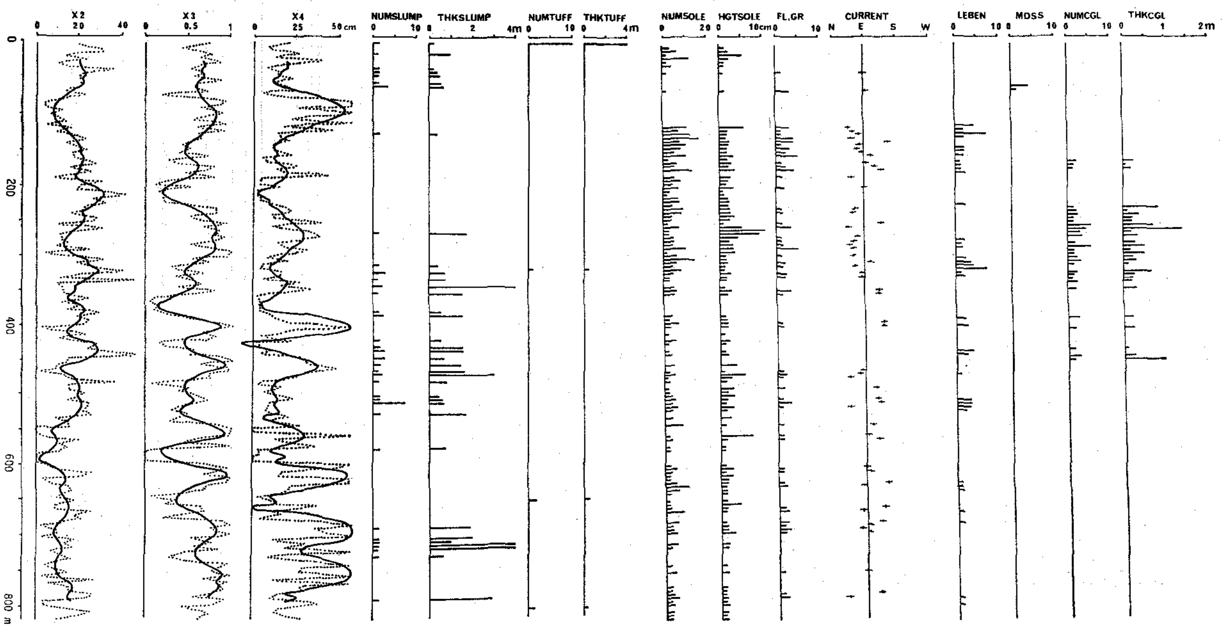

X2
0 20 40
X3
0 0.5 1
X4
0 25 50cm
NUMSLUMP
0 10
THKSLUMP
0 2 4m
NUMTUFF
0 10
THKTUFF
0 4m
NUMSOLE
0 20
HGTSOLE
0 10cm
FL.GR
0 10
CURRENT
N E S W
LEBEN
0 10
MOSS
0 10
NUMCGL
0 10
THKCGL
0 1 2m
0
200
400
600
800 m

Fig. 12. (b–v)

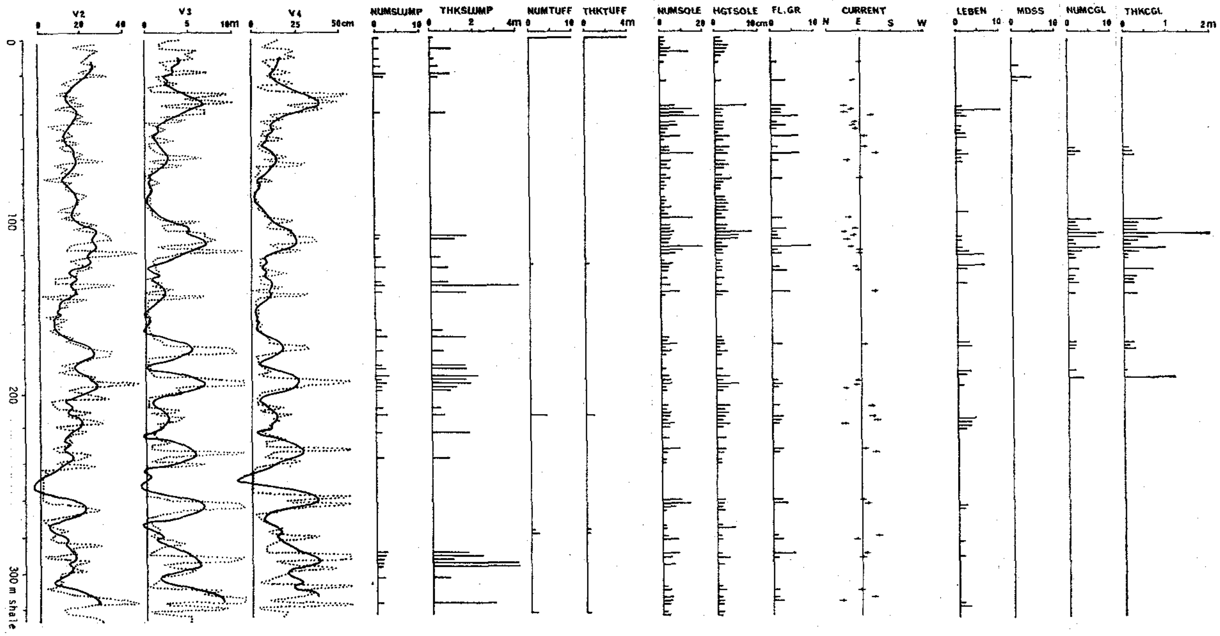

V2
V3
V4
NUMSLUMP
THKSLUMP
NUMTUFF
THKTUFF
NUMSOLE
HGTSOLE
FL.GR
CURRENT
N
E
S
W
LEBEN
MDSS
NUMCGL
THKCGL
0
100
200
300 m shale

Fig. 12. (b–N)

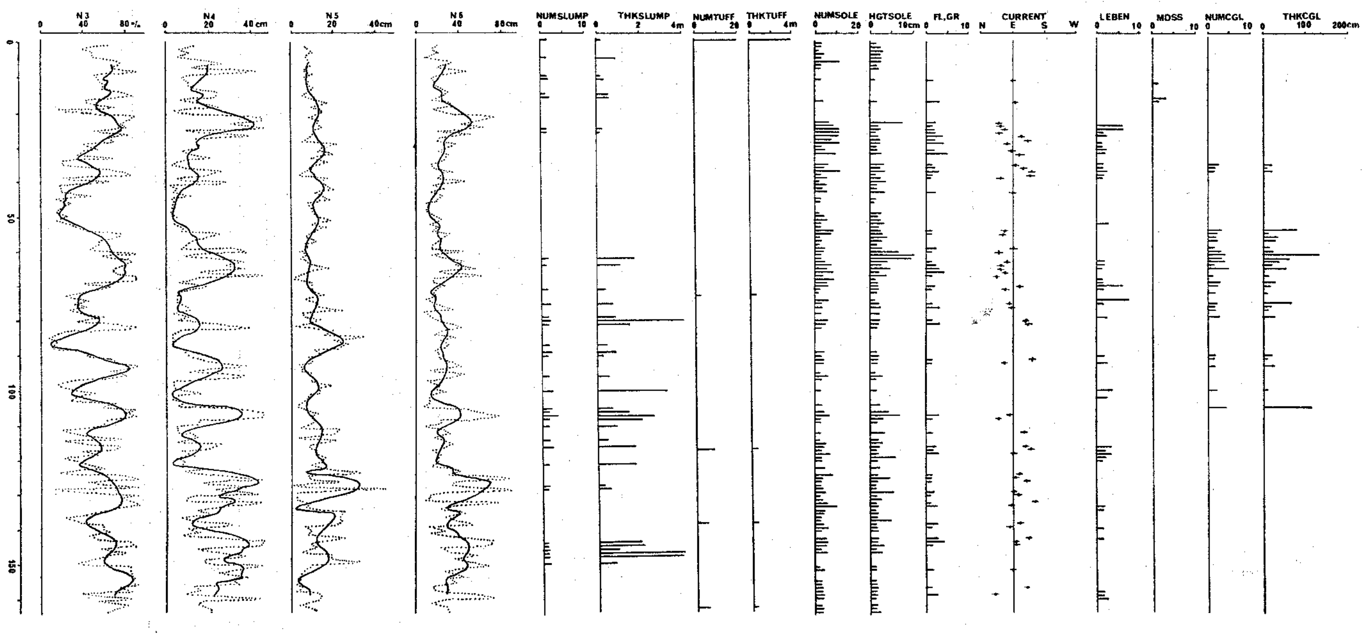

N3
N4
N5
N6
NUMSLUMP
THKSLUMP
NUMTUFF
THKTUFF
NUMSOLE
HGTSOLE
FL,GR
CURRENT
N E S W
LEBEN
MDSS
NUMCGL
THKCGL

Fig. 12. (c–x)

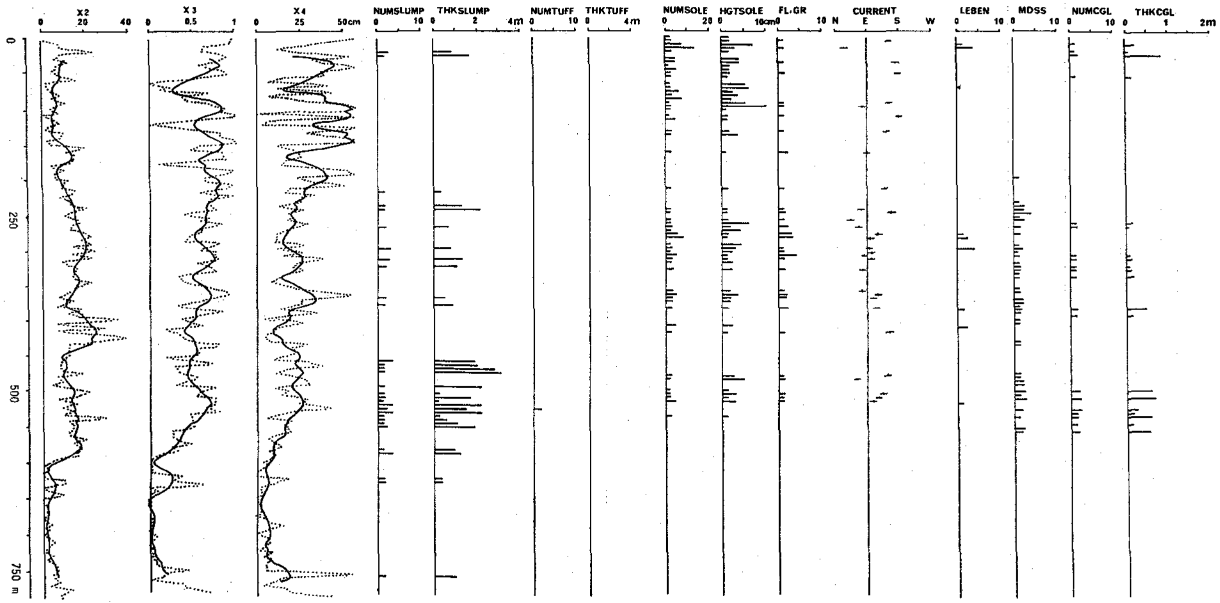

X2
0
20
40
X3
0
0.5
1
X4
0
25
50cm
NUMSLUMP
0
10
THKSLUMP
0
2
4m
NUMTUFF
0
10
THKTUFF
0
4m
NUMSOLE
0
20
HGTSOLE
0
10cm
FL.GR
0
10
CURRENT
N
E
S
W
LEBEN
0
10
MDSS
0
10
NUMCGL
0
10
THKCGL
0
1
2m
0
250
500
750 m

Fig. 12. (c–v)

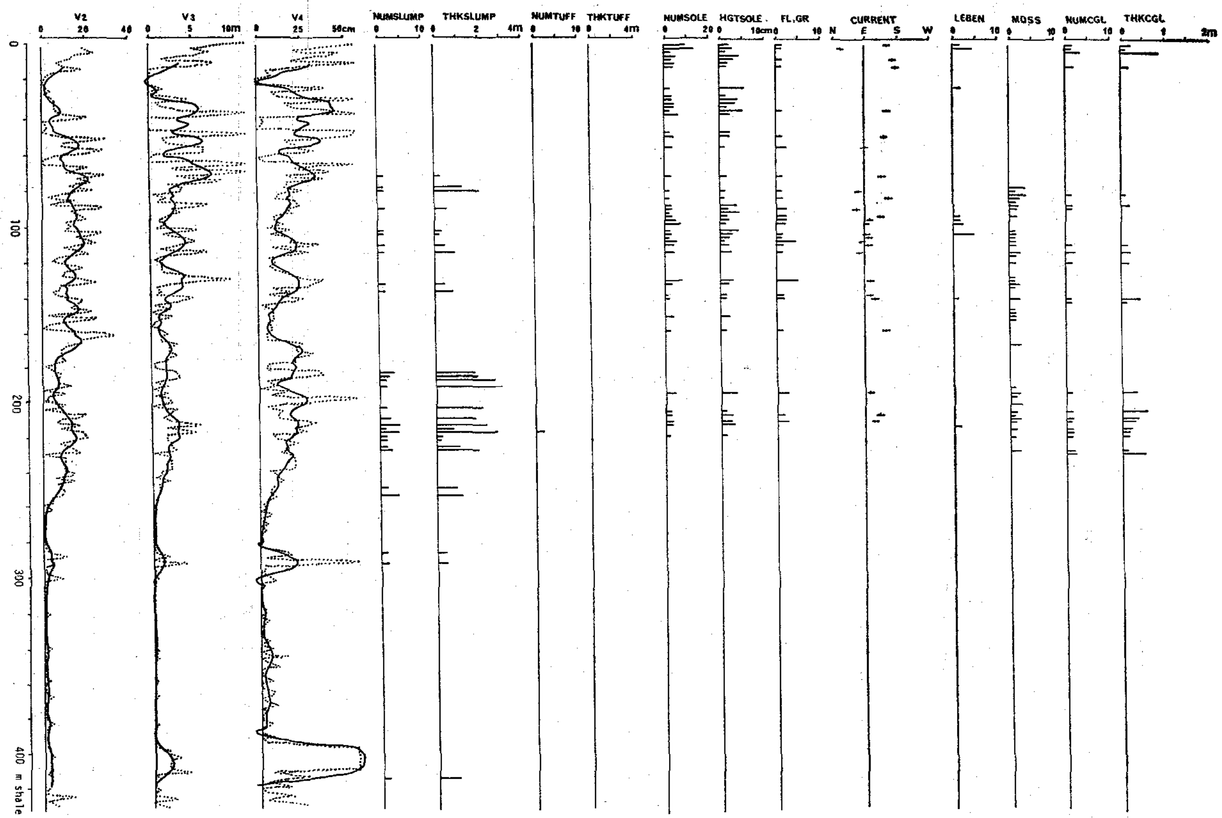

V2
V3
V4
NUMSLUMP
THKSLUMP
NUMTUFF
THKTUFF
NUMSOLE
HGTSOLE
FL.GR
CURRENT
N E S W
LEBEN
MOSS
NUMCGL
THKCGL
0
100
200
300
400 m shale

Fig. 12. (c–N)

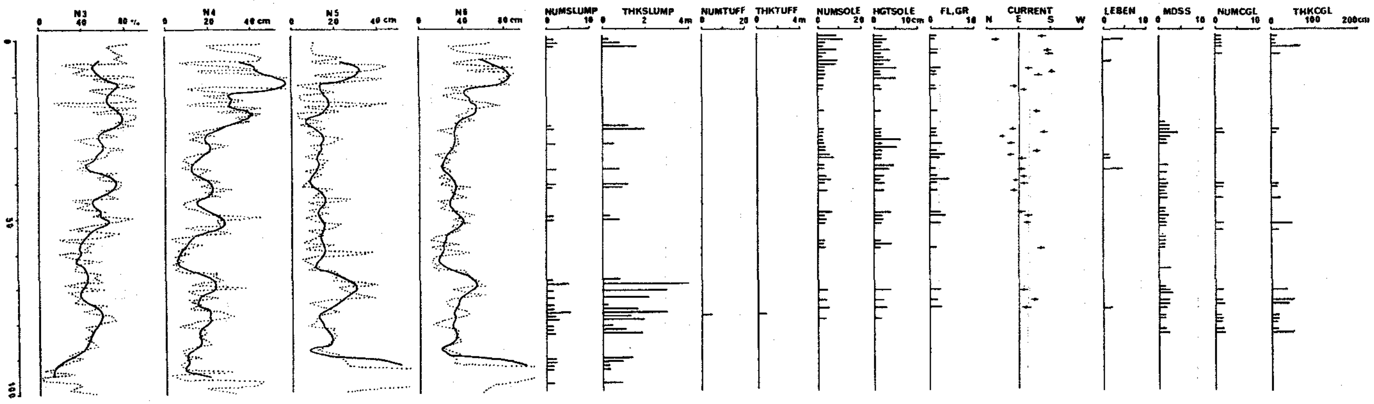


Fig. 12. (d–x)

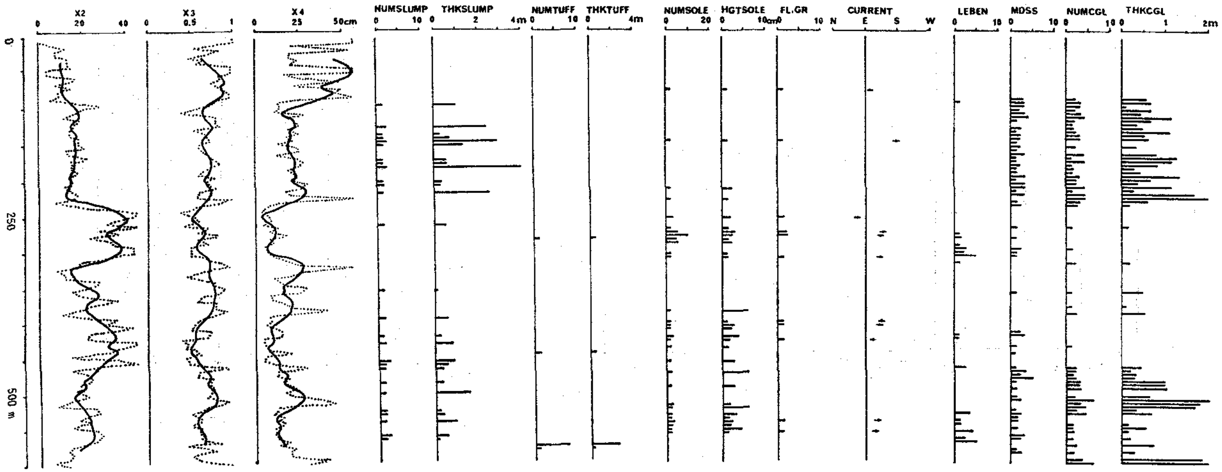


Fig. 12. (d–v)

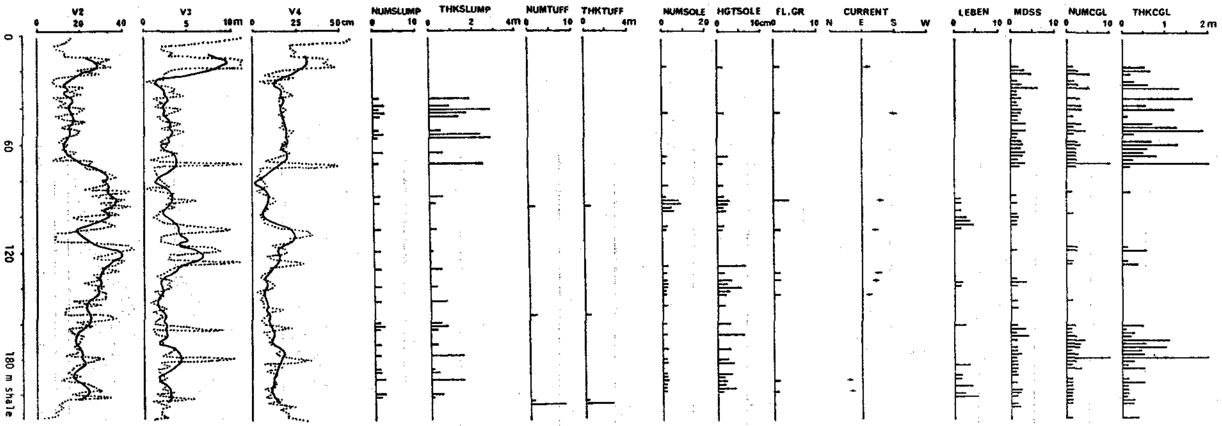


Fig. 12. (d–N)

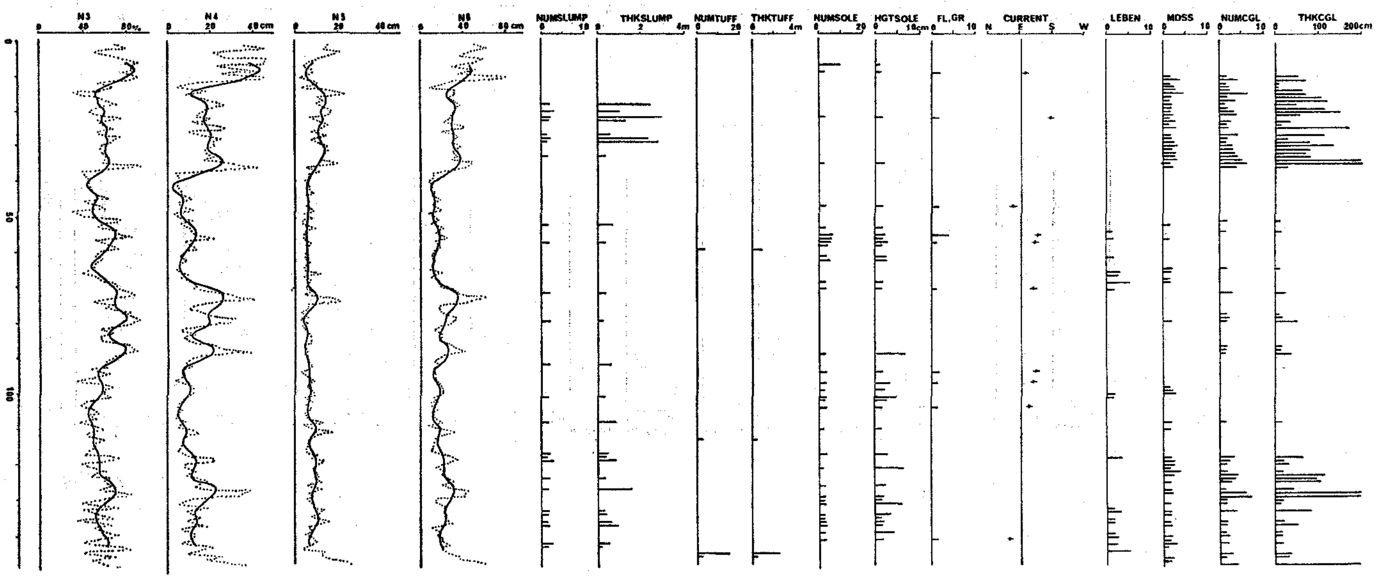


Fig. 12. (e–x)

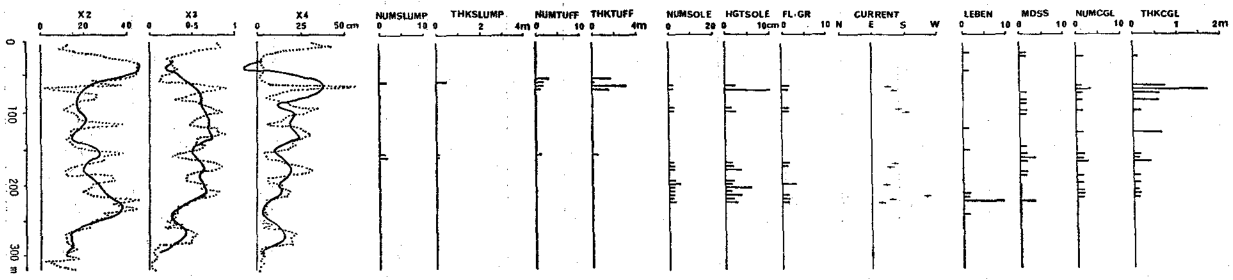


Fig. 12. (e–v)

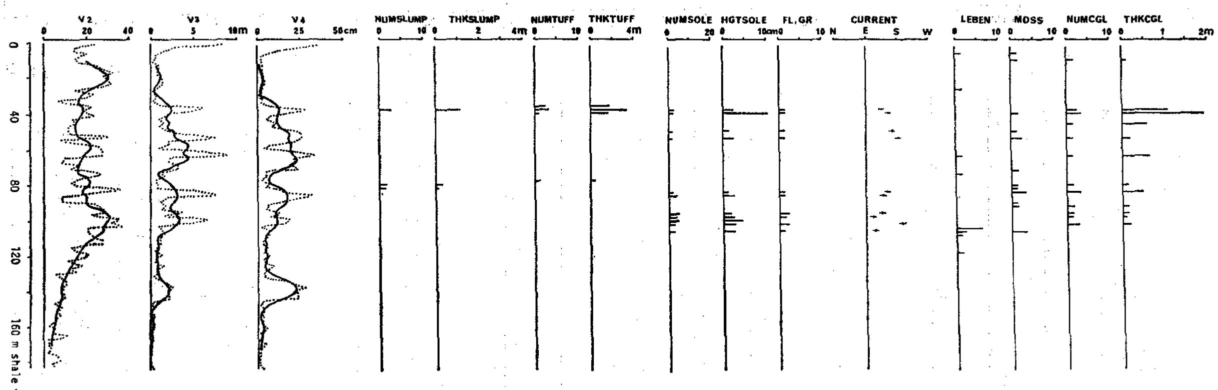


Fig. 12. (e–N)

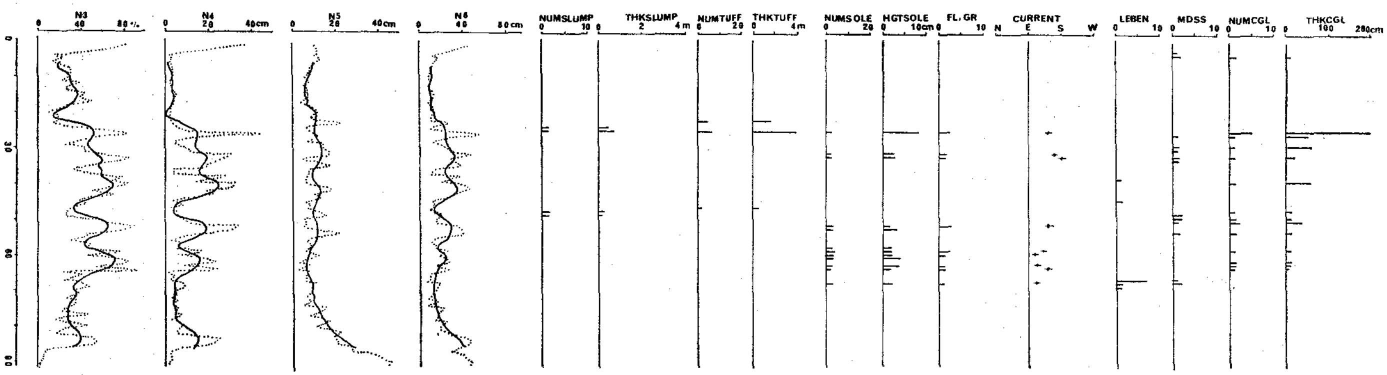


Fig. 12. Display of all the data in the system file. (a) FUKIAG column, (b) HOLVIL column, (c) TOTIBI column, (b) ANAIBI column, (e) YOROIZ column. (x) distance series, (v) thickness series, (N) number series. The dotted line shows original data and the solid one shows the smoothed data by the 11-term running average method.

III.2.b. Frequency Distribution of Bed Thickness

The frequency distribution of the bed thickness is calculated for each lithology in the file, but data of the slumped zone, muddy sandstone or conglomerate, and tuffs are omitted from the calculation. The observed values are divided into several classes in both of the linear and logarithmic scales, and the chi-square was calculated for each of the frequency distribution (Table 6a).

The number of the observed thickness of sandstone and shale are so large, exceeding 8,000, that the values of the chi-square for the two lithologies become large, and the normality of the frequency distribution is rejected. Comparing the values of the chi-square in the linear scale with those in the logarithmic scale, however, the latter are smaller than the former, especially for the sandstone. Consequently the frequency distribution in the logarithmic scale resembles the normal distribution than those in the linear scale.

The normality of the frequency distribution of the thickness of conglomerate is not rejected in the logarithmic scale. If the number of the observation increases, however, the value may become greater and the normality may be rejected.

From the result mentioned above it is suitable to use the logarithmic scale in the statistical analysis of the bed thickness data. It should be noticed that there is the restriction in interpreting the analyzed result since the frequency distribution is not normal.

III.2.c. Frequency Distribution of Variable

The normality of the frequency distribution of each variable of each series was examined as the foundation of the statistical analysis by calculating the chi-square (Table 6b).

The number of the observation of each variable, that is the number of case in this study, is about 600. As a result of the chi-square test the normality of the frequency distribution is rejected for all the variables except for two. The one is the number of sandstone in the thickness series in the linear scale, and the other one is the thickness of sandstone in the number series in the logarithmic scale.

Comparing the values of the chi-square in both scales, those of the number of sandstone are smaller in the linear scale than in the logarithmic scale, those of the thickness of sandstone and that of shale are in reverse, and those of the sandstone ratio are not remarkably different between in the both scales.

It is possible to determine the scale suitable for the statistical analysis for each variable, but the values of the chi-square are not so small that the both scales are used in this study.

Table 6. Chi-square test to examine the normality of the frequency distribution of the observed data. (a) on the thickness of each lithology, (b) on the variables used in this study.

(a)

LITHOLOGY	SCALE	INTERVAL	CHI-SQUARE	DEGREE OF FREEDOM	REJECT OR ACCEPT	SIGNIFICANCE LEVEL
conglomerate	linear	10 cm	57.58104	5	rejected	99.5 %
	logarithmic	$\log_2$	2.31666	3	not rejected	90.0
sandstone	linear	10 cm	14574.75000	6	rejected	99.5
	logarithmic	$\log_2$	1286.83228	6	rejected	99.5
shale	linear	10 cm	3507.10791	3	rejected	99.5
	logarithmic	$\log_2$	1360.76196	5	rejected	99.5

(b)

VARIABLE	SCALE	INTERVAL	CHI-SQUARE	DEGREE OF FREEDOM	REJECT OR ACCEPT	SIGNIFICANCE LEVEL
V2	linear	10	3.77044	2	not rejected	90.0 %
R2	logarithmic	ln	115.88297	1	rejected	99.5
V3	linear	100 cm	234.40677	6	rejected	99.5
R3	logarithmic	ln	283.32349	6	rejected	99.5
V4	linear	10 cm	164.46202	4	rejected	99.5
R4	logarithmic	ln	36.75558	3	rejected	99.5
X2	linear	10	26.73488	2	rejected	99.5
T2	logarithmic	ln	62.60318	1	rejected	99.5
X3	linear	0.1	66.60318	7	rejected	99.5
T3	logarithmic	ln	76.06616	1	rejected	99.5
X4	linear	10 cm	126.40488	4	rejected	99.5
T4	logarithmic	ln	24.23672	2	rejected	99.5
N3	linear	10	22.00244	7	rejected	99.5
L3	logarithmic	ln	26.86855	1	rejected	99.5
N4	linear	10 cm	69.70323	3	rejected	99.5
L4	logarithmic	ln	5.47334	2	not rejected	97.5
N5	linear	10 cm	92.80997	2	rejected	99.5
L5	logarithmic	ln	27.53955	1	rejected	99.5
N6	linear	10 cm	249.35445	5	rejected	99.5
L6	logarithmic	ln	24.15189	1	rejected	99.5

III.3. T Test

III.3.a. Purpose and Method

It is very rare that all items to be ovserved are measured in the field, and it is not clear whether the unobserved items in the field are originally absent or are not observed according to the limited condition of the outcrop. Therefore it is necessary to examine whether the observed value is affected or not by the values of other variables.

In each series a case is composed of fairly large number of beds, but in many cases many variables have no observed value. In the following the Student's t value is calculated on the number of sandstone, the sandstone ratio, the thickness of sandstone and that of shale, to examine whether their mean values show the difference or not between the groups of the case. The whole data are divided into two groups according to two kinds of criteria. The one is whether a variable has at least one observed value or a missing value, the other one is whether the paleocurrent direction is deviated to north or south from the east direction. The number of cases used in the calculation is same with the total number of case in each series in the former criterion, but is smaller than it in the latter criterion since only the cases are used which has a paleocurrent direction.

The Student's t is calculated as follows.

$$s^2 = \frac{(n_1-1)\cdot s_1^2+(n_2-1)\cdot s_2^2}{n_1+n_2-2}$$

$$s_d = \sqrt{\frac{s^2}{n_1}+\frac{s^2}{n_2}}$$

$$t = \frac{\bar{x}_1 \cdot \bar{x}_2}{s_d}$$

where n_1 and n_2 are the numbers of case in the two groups, and $\bar{x}_1$ and $\bar{x}_2$ are the sample means of the two groups. The F value is calculated to examine the difference of the variances of the two groups.

$$F = \frac{\max\,(s_1^2, s_2^2)}{\min\,(s_1^2, s_2^2)}$$

where **max** and **min** show the largest and smallest values of the values in the parentheses.

III.3.b. Effect of Presence of Value

The data are divided into two groups: one group is composed of cases which have observed value, and the other one is composed of the cases without observed value. It means that the cases in the latter group have the missing values in the system file. The number of cases in the latter group is generally larger than that in the former group. This division is performed by using all items as a grouping criterion.

The result of the *t* test for each variables is shown in Table 7, and significant differences between two respective groups are shown for many variables.

The variables having observed value are generally in the sandy part. It means that more items are observed in the part with larger number of sandstone, larger values of the sandstone ratio and the thickness of sandstone. It is consistent with the fact that the sandstone could preserve more information than the shale.

Against this fact, the more records of the slumped zone, the muddy sandstone, and fossils are observed in the part of thinner sandstone in the distance series, and the more records of fossils are observed in the part of thinner graded beds in the number series. The reason may be explained as follows. The thick sediments could be deposited by the event of short time period such as the submarine sliding, but in the distance series these sediments cannot be distinguished from the normal clastic sediments. The records of fossils are mainly represented by sand pipes in the shale, though preservation is poorer in the shale than in the sandstone. The observed record of fossils has affected by these two different functions, that is, original presence and its preservation.

It may be concluded from the *t* test that the presence or absence of values of some variables affect the value of the other variables. Only the cases with observed values are used in the calculation of statistics in the later analyses unless otherwise mentioned, and the cases with the missing value are excluded.

III.3.c. Effect of Paleocurrent Direction

The effect of the paleocurrent direction on the values of each variable is examined by using the *t* test (Table 8). The effect is not significant except the several variables. The number of sole marking and that of conglomerate are larger in the part of the southward current than that of northward one, and it is consistent with the fact that the source area of the Izumi Group was in the north of the basin.

The tuffs are observed only in the part of northward current, but the number of cases used in the calculation is too small to draw some meanings from this result.

The number of the muddy sandstone or conglomerate in all series and the thickness of the slumped zone in the number series are larger in the part of northward cur-

Table 7. T test to examine the difference of each variable between the groups classified according to the criterion whether the item of the variable is observed or not.

GROUPING VARIABLE	SERIES	NUMBER OF CASE		X2 or V2		X3 or V3 or N3		X4 or V4 or N4		N5		N6	
		PRESENT	ABSENT	PRESENT	ABSENT	PRESENT	ABSENT	PRESENT	ABSENT	PRESENT	ABSENT	PRESENT	ABSENT
SOLE MARKING	X	232	338	18.164	15.272	.653	.518	***	***	—	—	—	—
	V	201	467	21.169	11.230	424.792	154.452	20.482	12.539	—	—	—	—
	N	231	346	—	—	61.139	43.476	20.902	13.878	11.006	14.593	31.908	28.471
CURRENT MARKING	X	118	452	***	***	.699	.540	28.704	22.262	—	—	—	—
	V	97	551	21.721	13.009	521.075	188.601	23.392	13.526	—	—	—	—
	N	112	465	—	—	65.792	50.596	25.239	14.630	10.966	13.685	36.206	28.316
FLUTE TYPE	X	84	486	***	***	.694	.552	***	***	—	—	—	—
	V	71	574	21.405	13.399	529.173	200.879	23.982	13.845	—	—	—	—
	N	84	493	—	—	65.288	51.544	25.568	15.177	***	***	37.333	28.572
GROOVE TYPE	X	51	519	***	***	.677	.562	***	***	—	—	—	—
	V	46	602	22.391	13.696	500.378	218.349	21.842	14.480	—	—	—	—
	N	50	527	—	—	65.703	52.392	25.134	15.888	10.106	13.447	***	***
SLUMPED ZONE	X	122	448	18.156	15.984	.606	52.564	19.688	24.659	—	—	—	—
	V	121	527	18.223	13.416	361.716	210.493	20.448	13.753	—	—	—	—
	N	121	456	—	—	57.202	52.595	19.738	15.881	***	***	35.372	28.381
TUFF	X	21	549	***	***	***	***	***	***	—	—	—	—
	V	20	628	20.600	14.113	***	***	***	***	—	—	—	—
	N	19	558	—	—	***	***	***	***	***	***	***	***
FOSSIL RECORD	X	73	497	22.507	15.559	***	***	18.039	24.111	—	—	—	—
	V	71	577	21.239	13.461	398.691	218.642	18.666	14.552	—	—	—	—
	N	71	506	—	—	***	***	***	***	10.523	13.527	25.830	30.411
MUDDY SANDSTONE	X	130	440	18.977	15.702	.621	.556	18.551	25.085	—	—	—	—
	V	133	515	18.203	13.309	295.340	223.657	***	***	—	—	—	—
	N	131	446	—	—	***	***	***	***	***	***	***	***
CONGLOMERATE	X	124	446	18.868	15.868	.682	.542	***	***	—	—	—	—
	V	111	537	20.847	12.962	394.683	206.593	18.010	14.381	—	—	—	—
	N	122	455	—	—	62.107	51.250	19.132	16.035	10.302	13.923	***	***

***:not significant at 0.10 level. — :variable not present.

Table 8. T test to examine the difference of each variable between the groups classified according to the paleocurrent direction. GT90: northward current, LE90: southward current.

	X-SERIES		V-SERIES		N-SERIES	
VARIABLE	GT 90	LE 90	GT 90	LE 90	GT 90	LE 90
X2,V2	****	****	****	****		
	(73)	(45)	(63)	(34)		
X3,V3,N3	****	****	****	****	****	****
	(73)	(45)	(63)	(34)	(69)	(43)
X4,V4,N4	31.411	24.311	****	****	****	****
	(73)	(45)	(63)	(34)	(69)	(43)
N5					11.668	9.839
					(69)	(43)
N6					****	****
					(69)	(43)
NUMSOLE	2.7123	4.8889	3.7460	5.9118	3.2609	4.7442
	(73)	(45)	(63)	(34)	(69)	(43)
HGTSOLE	****	****	****	****	****	****
	(73)	(45)	(63)	(34)	(69)	(43)
FL	****	****	****	****	1.3208	1.6129
	(53)	(31)	(49)	(25)	(53)	(31)
GR	****	****	****	****	****	****
	(29)	(22)	(25)	(21)	(29)	(21)
THKSLUMP	****	****	****	****	151.13	86.25
	(13)	(11)	(11)	(14)	(15)	(12)
NUMSLUMP	****	****	****	****	****	****
	(13)	(11)	(11)	(14)	(15)	(12)
THKTUFF	232.00	0.00	285.00	0.00	****	****
	(2)	(0)	(5)	(0)	(3)	(0)
NUMTUFF	2.0	0.0	6.80	0.00	6.0	0.0
	(2)	(0)	(5)	(0)	(3)	(0)
LEBEN	****	****	****	****	****	****
	(21)	(20)	(19)	(18)	(16)	(18)
MDSS	1.9444	1.4286	****	****	1.8000	1.2857
	(18)	(7)	(21)	(6)	(15)	(7)
THKCGL	****	****	****	****	****	****
	(17)	(14)	(20)	(13)	(17)	(14)
NUMCGL	****	****	1.4000	3.0769	1.3529	1.9286
	(17)	(14)	(20)	(13)	(17)	(14)

Number in parentheses shows number of case in the group.
**** not significant at 0.20 level.

rent than in the part of southward one. The result is inconsistent with the general opinion on the source area and the transportation direction of the sandstone. If these sediments and the structure are considered to be caused by the submarine sliding, it is suggested that the submarine sliding had the different origin from that of the deposition of the sandstone.

III.4. Correlation Analysis

III.4.a. Purpose and Method

The correlation coefficient is calculated to examine the relation between two variables. Many types of coefficient are proposed, most popular one is adopted in this paper. The Pearson's correlation coefficient (r) is calculated:

$$r=\frac{\sum_{i=1}^{n}(x_i-\bar{x})\cdot(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2\cdot\sum_{i=1}^{n}(y_i-\bar{y})^2}}$$

where n is the number of cases, $\bar{x}$ and $\bar{y}$ are the means of observed x and y.

The correlation coefficient expects the normal distribution for the frequency distribution of the data. The data used in this study, however, never satisfy this condition as discussed in III.2.c., and there is some limitation in interpreting the value of the coefficient.

The scatter diagrams were also given for several pairs of variable, not only to display the correlation, but also to avoid uncertain interpretation of the values of the correlation coefficient.

III.4.b. Scatter Diagram

The scatter diagrams are shown in Figure 13a–c for the pairs of variables on the number of sandstone, the sandstone ratio, the thickness of sandstone and that of shale. The higher correlations are shown generally in the logarithmic scale than in the linear scale for both of the paired variables. There are several exceptions such as the diagram between the sandstone ratio and the thickness of sandstone in the number series, that is, the higher correlation is shown in the semilogarithmic graph.

Several diagrams in the number series and in the distance series have the boundary, in one side of the boundary all cases are plotted. Those boundaries are expressed:

$$X2\cdot X4\leqq 500$$

$$N4\leqq N6$$

and so on. The correlation coefficients of such diagrams are affected by the presence of the boundary, and the values should have some limitation in their application.

Fig. 13. Scatter diagram between the variables. Explanations of variable codes are given in Table 3. (a) distance series, (b) thickness series, (c) number series.

(a)

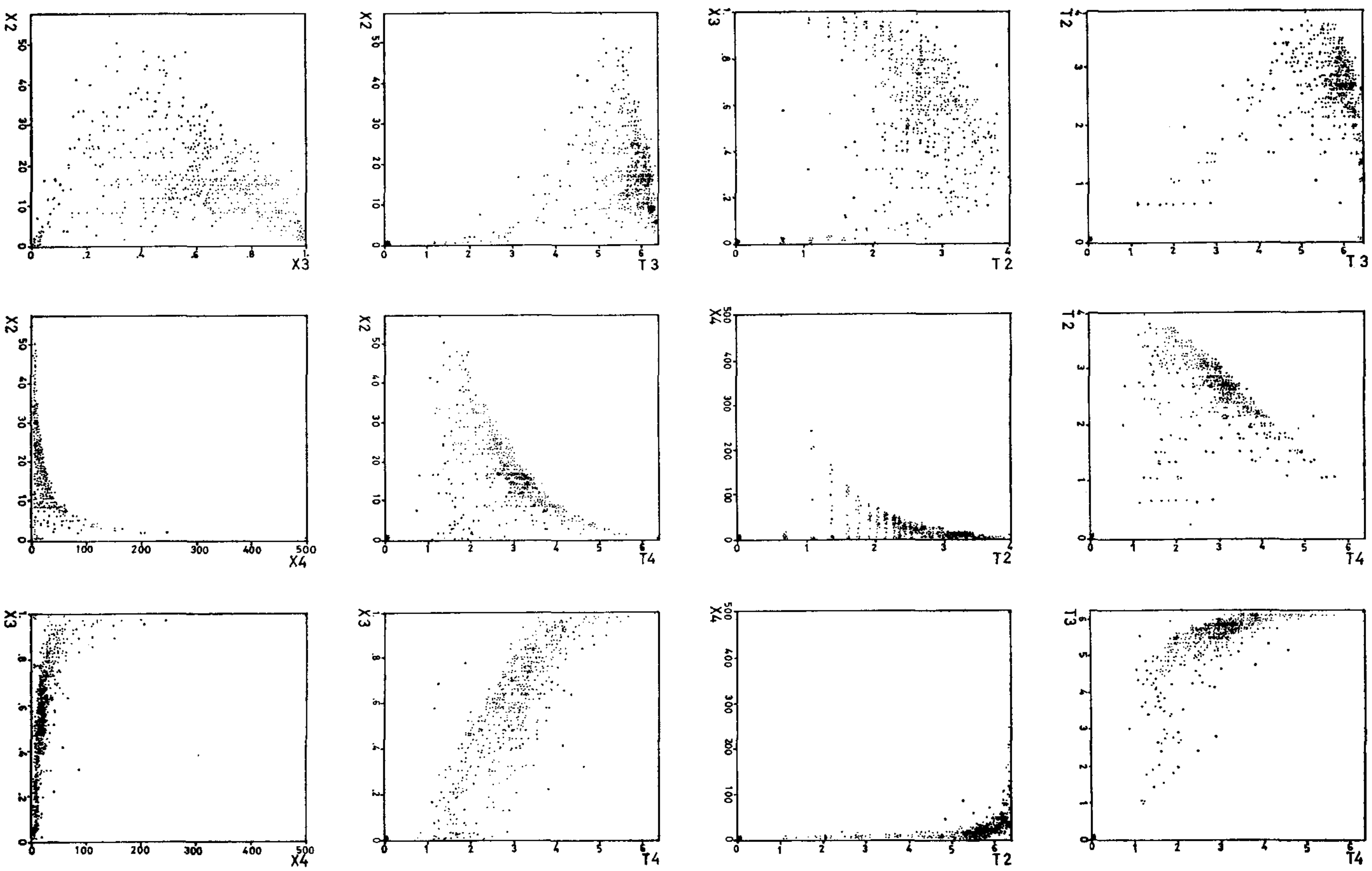


Fig. 13. (b)

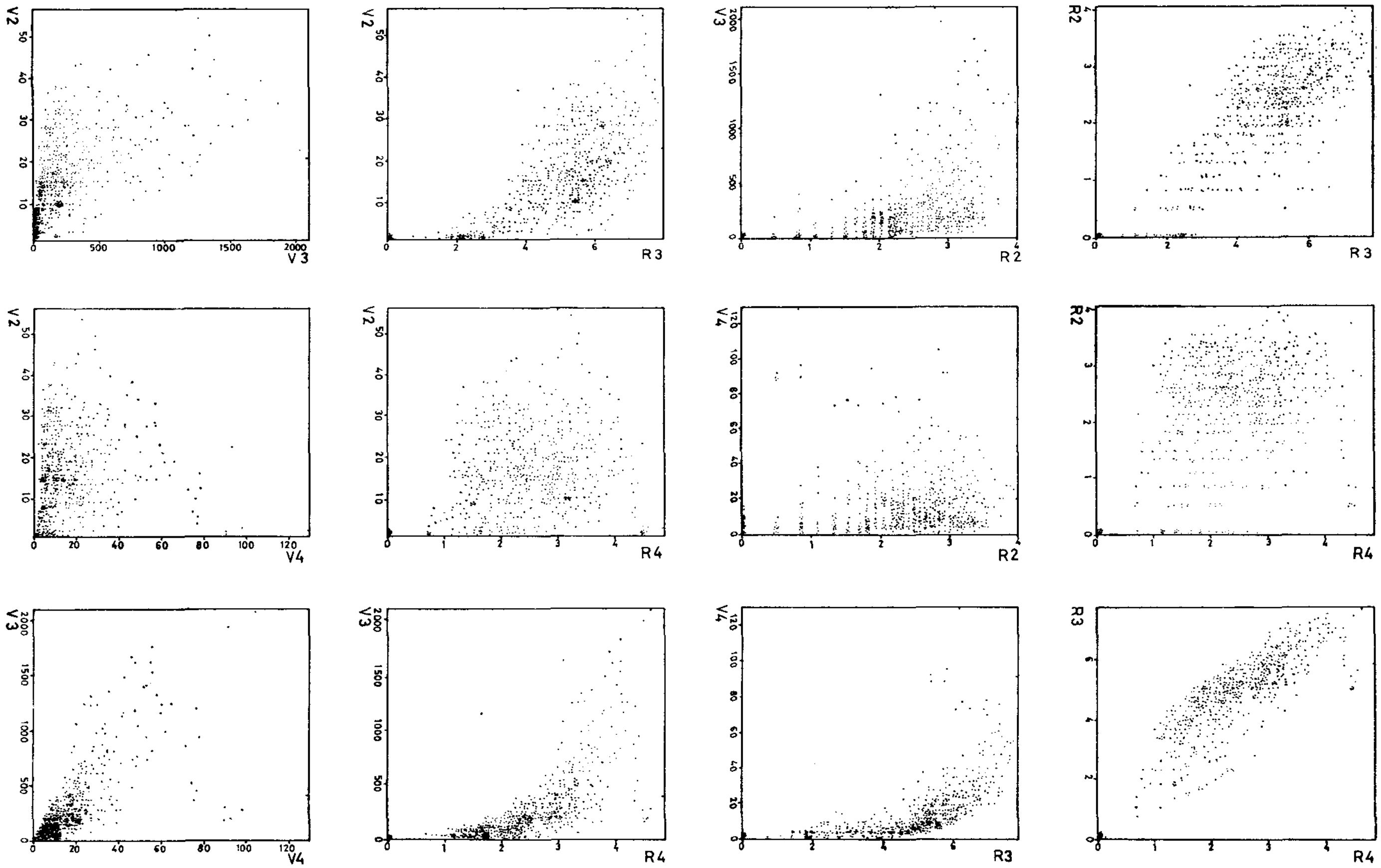


Fig. 13. (c)

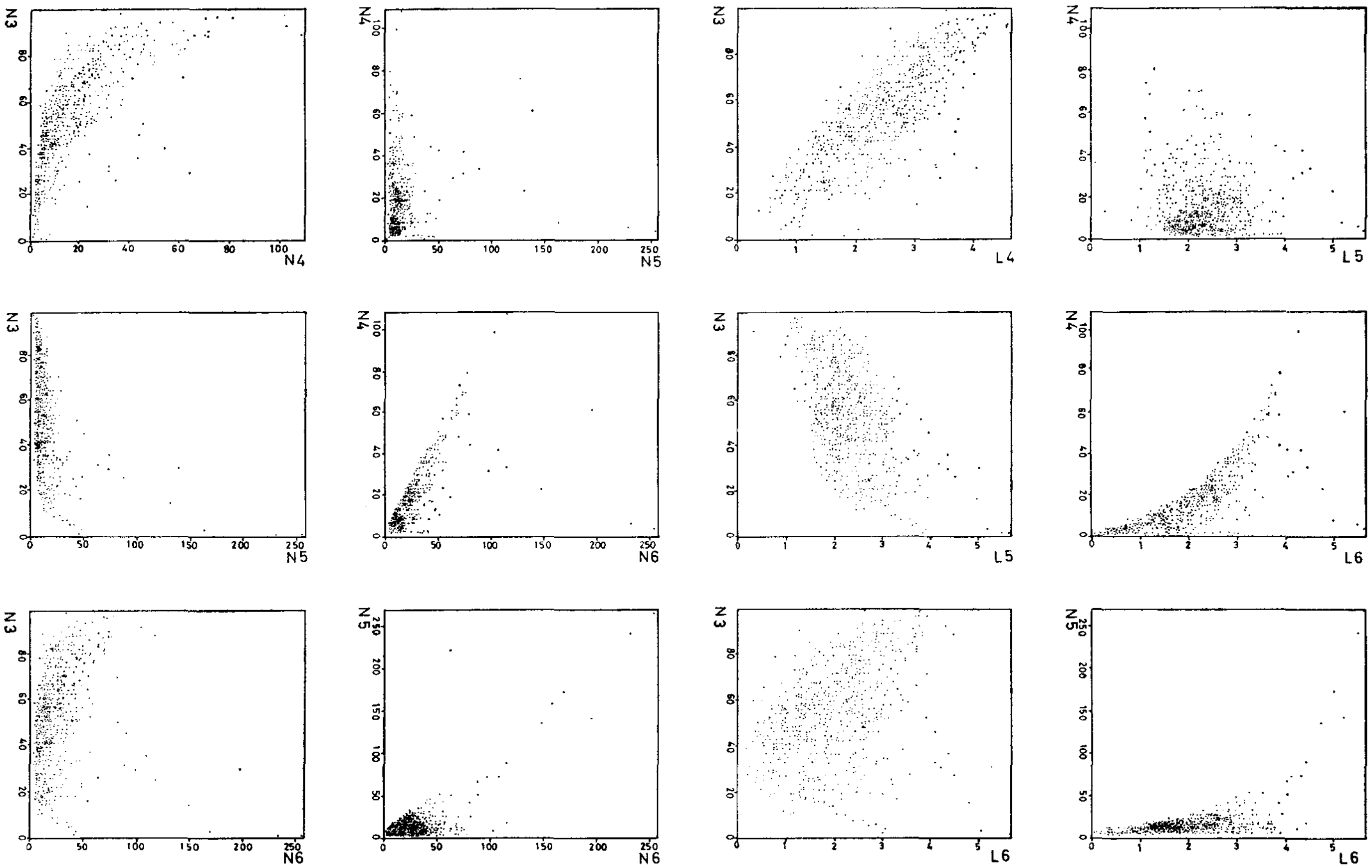
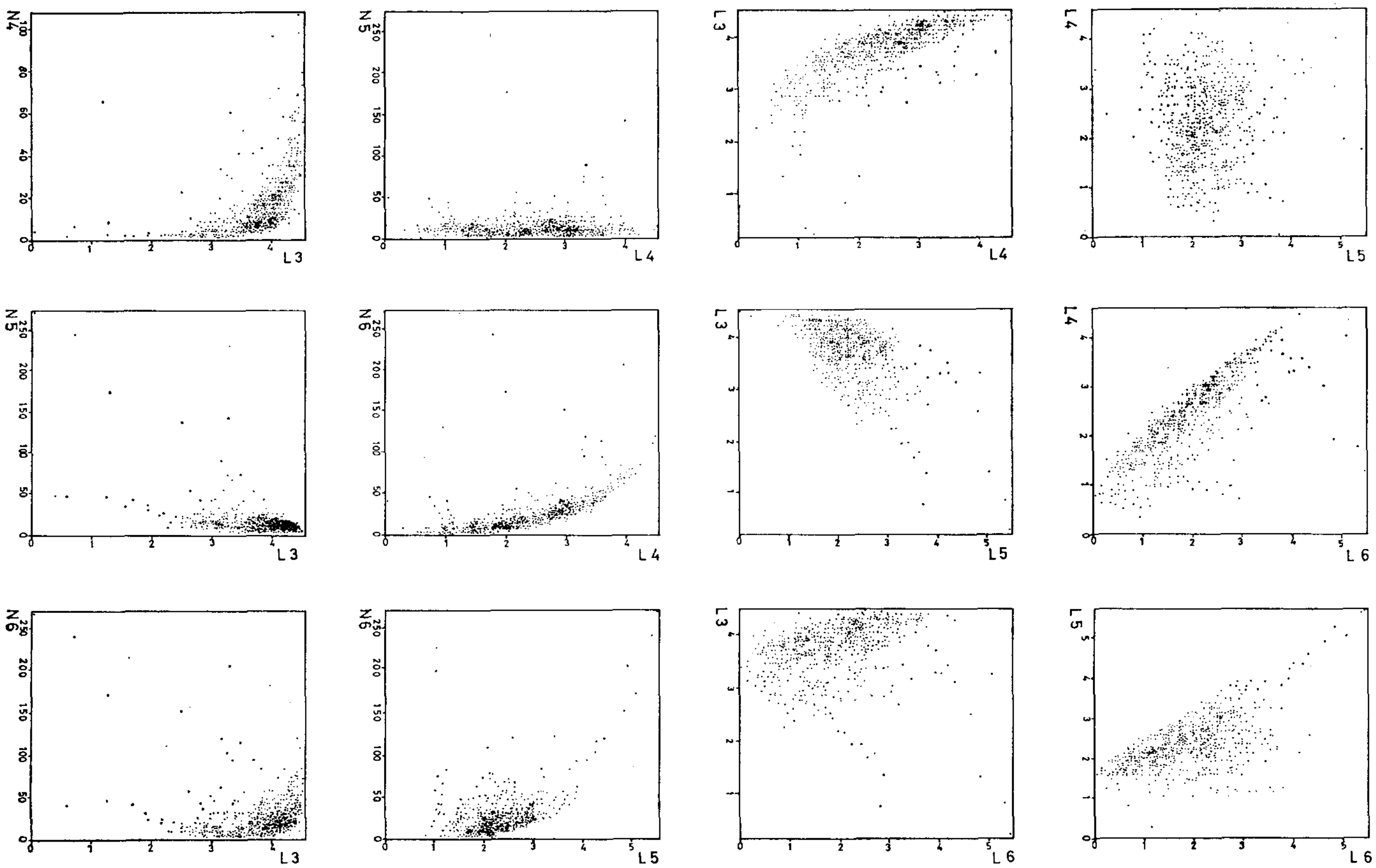


Fig. 13. (c) continued



III.4.c. Correlation among Variables

All the data of the five columns are used to calculate the correlation coefficient as a whole, and cases which have the missing value in one or both of the paired variables are excluded (Tables 9a–c). Generally it is clear that the absolute values of the correlation coefficient are small. The number of case of several pairs of variable is too small to calculate the correlation coefficient in each series. The correlation coefficients between variables on same item show high correlation although several exceptions are also shown.

The differences among the correlation coefficient matrices in the three series are not so clear as a whole, but for several pairs of variables the values are quite different. For example the correlation between the number of sandstone and that of tuff is negative in the distance series, but it is not significant in the thickness series.

Attentions should be paid on the weakness of the correlation between FL and GR in the distance series and thickness series. It suggests that there are two different kinds of currents from the view point of current markings: the one produces the flute-type current markings, and the other the groove-type ones.

The large values of the correlation coefficient do not always suggest the presence of the high correlation between the paired variables, and some of them are resulted from the samll number of cases used in the calculation. The latter examples are distinguished by adding an underline in the tables of correlation coefficient matrices.

III.4.d. Trend and Residue

All cases have values on the number of sandstone, the sandstone ratio, the thickness of sandstone and that of shale, and it is possible for these variables to separate the trend of change from the residue by means of the running average method which will be discussed in III.5.a. The correlation coefficients between these variables are shown in Tables 10a–d.

It may be said that there are no significant difference among the correlation coefficients on the original values, the trend and the residue when using all cases of the five columns as a whole. The followings are in common. In the distance series the number of sandstone and the thickness of sandstone show the negative correlation, and the thickness of sandstone and the sandstone ratio show the positive one. In the thickness series the number of sandstone, the total thickness and the mean thickness of sandstone show positive correlation with each pair, but the correlation between the number and thickness of sandstone is not so remarkable. In the number series the sandstone ratio and the thickness of sandstone show the positive correlation, the thickness of sandstone or shale and the thickness of the graded bed show the positive

Table 9. Correlation coefficient among variables. The symbol *** shows that the coefficient cannot be computed because of insufficiency of the number of case. The underlined coefficient is to be noticed because the number of cases used in the calculation is less than 10. The coefficient in the parentheses is calculated for the two variables on the same item. The cases which have no observed value in one or both of the paired variables are excluded from the calculation of the coefficient for the pair. (a) distance series, (b) thickness series, (c) number series.

(a)

	NUMSOLE	HGTSOLE	CURRENT	FL	GR	THKSLUMP	NUMSLUMP	THKTUFF	NUMTUFF	THKCGL	NUMCGL	MDSS	LEBEN	
X2	.1008	-.1406	-.0483	.2252	.0785	-.2776	.0334	-.3418	-.2887	-.2738	-.1007	.0447	.1451	X2
T2	.1561	-.1306	-.1061	.2247	.1437	-.2945	.0641	-.3012	-.1963	-.2613	-.0569	.0711	.1749	T2
X3	-.0514	.0861	.0590	.0324	-.1278	.0272	.0077	.1590	.2148	.3134	.2584	-.0106	-.1177	X3
T3	-.0088	.0849	.0374	.0601	-.0959	.0276	.0423	.1322	.1928	.2949	.2543	-.0120	-.0691	T3
X4	-.1426	.0577	.1299	-.1354	-.1489	.1899	-.0782	.1222	-.0207	.2806	.0886	-.0924	-.0914	X4
T4	-.1261	.1528	.1264	-.1401	-.1373	.2028	-.0488	.2949	.2151	.3603	.1883	-.0706	-.1758	T4
NUMSOLE	1.0000	(.0061)	-.3447	(.4629)	(.5760)	-.1405	.0601	-.5289	-.4286	-.1037	.1558	-.0855	.0755	NUMSOLE
HGTSOLE		1.0000	-.0385	.0498	-.0587	-.0836	-.0809	.1969	-.3002	.4434	.4024	.1497	-.0633	HGTSOLE
CURRENT			1.0000	-.1464	.0394	.2542	.1305	***	***	-.0236	-.2171	-.0985	-.1337	CURRENT
FL				1.0000	.1416	.3575	-.0788	***	***	-.1246	.4484	-.2385	-.2334	FL
GR					1.0000	.0132	.8779	***	***	***	***	-.2402	-.0876	GR
THKSLUMP						1.0000	(.1836)	-.3228	-.4000	.0693	-.0832	-.1239	-.3646	THKSLUMP
NUMSLUMP							1.0000	-.2749	-.3367	-.2452	-.3227	.0684	-.1143	NUMSLUMP
THKTUFF								1.0000	(.9088)	.5010	.1947	-.1992	***	THKTUFF
NUMTUFF									1.0000	-.2060	-.4082	-.3131	***	NUMTUFF
THKCGL										1.0000	(.7094)	.1739	-.1916	THKCGL
NUMCGL											1.0000	.4211	.0302	NUMCGL
MDSS												1.0000	.3583	MDSS
LEBEN													1.0000	LEBEN

(b)

	NUMSOLE	HGTSOLE	CURRENT	FL	GR	THKSLUMP	NUMSLUMP	THKTUFF	NUMTUFF	THKCGL	NUMCGL	MDSS	LEBEN	
V2	.1916	-.0194	.0330	.2171	.3247	-.1833	.0338	.0749	.0731	.1028	.2511	-.0479	.1324	V2
R2	.1818	-.0179	-.0103	.1668	.3208	-.1635	.0670	.0120	.0339	.1002	.2266	-.0326	.1480	R2
V3	.3568	.0330	-.0019	.2710	.2460	.1907	.1882	.3872	.3445	.3235	.3716	.0038	-.0617	V3
R3	.3554	.1126	-.0250	.2639	.2952	.1625	.2077	.3458	.3705	.2911	.3363	.0399	-.0171	R3
V4	.2500	.0802	-.0036	.1878	.1012	.3058	.1486	.4484	.4247	.3173	.2823	.0621	-.1064	V4
R4	.3010	.1403	-.0216	.2246	.1476	.3264	.2024	.4312	.4413	.3320	.2856	.0866	-.1002	R4
NUMSOLE	1.0000	(.0650)	-.3427	(.5869)	(.5700)	.1197	.0370	-.5415	-.4351	-.0747	.1820	-.1027	.1905	NUMSOLE
HGTSOLE		1.0000	-.0706	.0100	.0009	-.1105	-.0017	-.1019	-.2354	.1954	.1666	.0260	-.1512	HGTSOLE
CURRENT			1.0000	-.1336	.0064	.0532	-.0885	.8594	.6571	-.1237	-.3134	.0332	.0038	CURRENT
FL				1.0000	.0783	.3100	.0891	***	***	.0898	.2729	-.2204	-.3078	FL
GR					1.0000	-.0544	-.4444	***	***	.6719	.6681	***	-.1404	GR
THKSLUMP						1.0000	(.2306)	-.6609	-.7398	.3740	.3117	.0858	-.3334	THKSLUMP
NUMSLUMP							1.0000	-.7141	-.6666	-.0172	-.0962	.1568	-.1611	NUMSLUMP
THKTUFF								1.0000	(.9115)	.3561	.3441	-.4401	***	THKTUFF
NUMTUFF									1.0000	-.3471	-.3656	-.3971	***	NUMTUFF
THKCGL										1.0000	(.8358)	.1141	-.5239	THKCGL
NUMCGL											1.0000	.2841	-.3360	NUMCGL
MDSS												1.0000	-.2655	MDSS
LEBEN													1.0000	LEBEN

Table 9. continnued

(C)

	NUMSOLE	HGTSOLE	CURRENT	FL	GR	THKSLUMP	NUMSLUMP	THKTUFF	NUMTUFF	THKCGL	NUMCGL	MDSS	LEBEN	
N3	.1456	.1817	-.0582	.1521	.0876	.1419	.0569	.1537	.1483	.1499	.1674	-.1248	-.0593	N3
N4	.1876	.2305	.0620	.1463	-.0746	.2810	.0858	.4394	.2384	.3224	.2373	-.0122	-.0373	N4
N5	.0608	-.0794	.2148	-.0776	-.1115	-.0318	-.0550	.5289	.2896	.1269	.0090	.1653	-.1078	N5
N6	.1922	.1568	.1331	.1091	-.0985	.1211	-.0007	.6459	.3520	.3648	.2314	.1049	-.0778	N6
L3	.1449	.1669	-.0819	.1324	.0925	.1560	.0803	.1001	.1525	.1569	.1824	-.1011	-.0907	L3
L4	.2350	.1903	.0332	.1756	-.0001	.2980	.1083	.4203	.3040	.3303	.2644	.0686	-.1212	L4
L5	.0914	-.0620	.1147	-.0858	-.1134	.1195	.0453	.2282	.1143	.1526	.0588	.2553	-.0745	L5
L6	.2287	.1487	.0977	.1464	-.0537	.2410	.0682	.5397	.3289	.3656	.2499	.1637	-.1110	L6
NUMSOLE	1.0000	(.0551)	-.2297	(.3667)	(.3818)	-.0122	-.0237	-.1214	-.7071	-.1899	-.0650	-.0692	.2348	NUMSOLE
HGTSOLE		1.0000	-.1471	.1752	.0089	-.0027	-.0073	.9994	.5695	.2492	.3830	.1045	-.0820	HGTSOLE
CURRENT			1.0000	-.1555	.0802	.4553	.2790	.6178	.9912	.0376	-.1790	.0956	-.1177	CURRENT
FL				1.0000	.6675	.1128	.0	1.0000	.5000	.2584	.3834	-.0487	-.2700	FL
GR					1.0000	***	***	***	***	.2640	-.1111	***	-.0480	GR
THKSLUMP						1.0000	(.4744)	-.9927	-.9019	-.1250	-.3067	.0417	.0602	THKSLUMP
NUMSLUMP							1.0000	-.7603	-.3515	-.0986	-.1741	-.0040	.2209	NUMSLUMP
THKTUFF								1.0000	(.8281)	.9043	.9656	-.9769	***	THKTUFF
NUMTUFF									1.0000	.0472	.2393	-1.0000	***	NUMTUFF
THKCGL										1.0000	(.7932)	.2193	-.1611	THKCGL
NUMCGL											1.0000	.4670	.0344	NUMCGL
MDSS												1.0000	-.2964	MDSS
LEBEN													1.0000	LEBEN

one, and the sandstone ratio and the thickness of shale show negative one, but the thickness of sandstone and that of shale show no correlation.

Considering the result several differences become clear among the columns. In the TOTIBI column in the distance series, the number and thickness of sandstone show the positive correlation. In the ANAIBI column, in the thickness series the trends of the number and the thickness of sandstone show the negative correlation, and in the number series the thickness of sandstone and that of shale show the positive one.

There is a more convenient way to examine the presence of the linear trend of change in the column. It is to calculate the correlation coefficients between these variables and a system variable SEQNUM which shows the order of case in the column. Of course this method has fairly large limitation, but it may be suggested that the sandstone ratio in the TOTIBI column in the distance series and the number of sandstone in the YOROIZ column in the thickness series have the linear trend (Table 11).

Table 10. Correlation coefficient on the trend of change and the residue. The value of trend is calculated by the 11-term running average method. (a) all data of the five columns are used as a whole, (b) calculated for each column in the distance series, (c) calculated for each column in the thickness series, (d) calculated for each column in the number series.

(a)

	ORIGINAL	TREND	RESIDUE		ORIGINAL	TREND	RESIDUE
X2:X3	-.0955	.0235	-.3003	N3:N4	.6972	.7298	.6648
X2:T3	.2204	.3373	-.0015	N3:L4	.8076	.8313	.7618
T2:X3	.0904	.2537	-.1608	L3:N4	.5621	.6057	.5512
T2:T3	.4903	.6097	.3160	L3:L4	.7266	.7476	.7171
X2:X4	-.3747	-.4324	-.4935	N3:N5	-.3718	-.2992	-.4832
X2:T4	-.3688	-.3013	-.4742	N3:L5	-.5531	-.4730	-.6570
T2:X4	-.3415	-.2668	-.4783	L3:N5	-.5462	-.4741	-.6240
T2:T4	-.0910	.0094	-.1623	L3:L5	-.5853	-.5346	-.6087
X3:X4	.4924	.6819	.4756	N3:N6	.1360	.2359	.1419
X3:T4	.7721	.8437	.6310	N3:L6	.3291	.4233	.2661
T3:X4	.3149	.4605	.2744	L3:N6	-.0820	.0352	-.0558
T3:T4	.6975	.7311	.6324	L3:L6	.1429	.2644	.1326
V2:V3	.5815	.5852	.6047	N4:N5	.0242	.1325	-.1734
V2:R3	.7087	.7685	.5744	N4:L5	.0035	.1017	-.1626
R2:V3	.5239	.5588	.5388	L4:N5	.0126	.0979	-.1120
R2:R3	.8522	.8843	.7666	L4:L5	.0150	.0840	-.0611
V2:V4	.1320	.0798	.1563	N4:N6	.6287	.7091	.6437
V2:R4	.3671	.4301	.2188	N4:L6	.7658	.8361	.7057
R2:V4	.1902	.1258	.2598	L4:N6	.5491	.7476	.5670
R2:R4	.5122	.5617	.3818	L4:L6	.7836	.8382	.7859
V3:V4	.6810	6286	.6855	N5:N6	.7926	.7928	.6420
V3:R4	.6615	.7336	.5751	N5:L6	.5117	.5314	.3944
R3:V4	.5875	.5168	.6767	L5:N6	.5783	.5960	.5670
R3:R4	.8851	.8826	.8847	L5:L6	.5505	.5611	.7859

Table 10. continued

(b)

COLUMN	FIKIAG			HOLVIL			TOTIBI			ANAIBI			YOROIZ		
VARIABLE	ORIGINAL	TREND	RESIDUE	ORIGINAL	TREND	RESIDUE	ORIGINAL	TREND	RESIDUE	ORIGINAL	TREND	RESIDUE	ORIGINAL	TREND	RESIDUE
X2:X3	.3168	-.3845	-.0546	-.3839	-.3990	-.3655	.3269	.5171	-.0250	-.6447	-.7807	-.5778	-.2825	-.4430	-.5130
X2:T3	.1391	.1671	.2331	-.0216	-.0053	-.0808	.5311	.6910	.1817	-.6503	-.7932	-.5733	.0125	-.2932	-.3716
T2:X3	-.0190	-.1708	.3617	-.2894	-.2929	-.3103	.4732	.6677	.0563	-.6526	-.7912	-.5764	-.2295	-.3939	-.6015
T2:T3	.5083	.4280	.6948	.1665	.1756	.2481	.7480	.8510	.5046	-.6301	-.7872	-.5379	.1013	-.2272	-.4869
X2:X4	-.5248	-.7541	-.5141	-.5222	-.5947	-.5202	-.1541	.0358	-.3178	-.4160	-.7651	-.5888	-.4563	-.5501	-.6025
X2:T4	-.4904	-.6104	-.2688	-.4615	-.4792	-.5015	.1448	.4233	-.2154	-.8891	-.9635	-.8733	-.5513	-.7728	-.7493
T2:X4	-.4418	-.5948	-.2861	-.5065	-.4914	-.5773	-.0165	.2396	-.1312	-.6582	-.8581	-.8148	-.5727	-.6193	-.8541
T2:T4	-.1469	-.3914	.2245	-.2280	-.2537	-.2697	.4376	.6519	.1965	-.9623	-.9807	-.9455	-.5232	-.7441	-.8813
X3:X4	.7190	.8245	.5563	.5666	.7035	.4481	.5724	.8016	.4265	.4375	.8058	.5947	.6173	.6259	.6421
X3:T4	.8583	.9390	.8543	.7452	.8256	.6506	.7413	.8927	.3983	.7926	.8903	.7809	.9139	.8904	.8806
T3:X4	.4415	.4406	.3589	.3669	.4719	.2471	.4366	.6831	.2892	.3971	.7734	.5309	.4563	.5385	.5636
T3:T4	.7664	.6610	.8396	.6721	.7017	.5933	.7962	.9163	.5798	.7728	.8882	.7503	.7924	.8185	.8374

(c)

COLUMN	FUKIAG			HOLVIL			TOTIBI			ANAIBI			YOROIZ		
VARIABLE	ORIGINAL	TREND	RESIDUE	ORIGINAL	TREND	RESIDUE	ORIGINAL	TREND	RESIDUE	ORIGINAL	TREND	RESIDUE	ORIGINAL	TREND	RESIDUE
V2:V3	.5482	.4973	.6350	.6626	.6964	.5881	.6882	.7332	.6749	.3907	.2649	.5783	.4928	.4417	.5851
V2:R3	.7354	.8421	.5501	.7329	.8122	.6360	.7728	.8470	.6251	.4351	.2610	.6689	.6467	.6335	.5689
R2:V3	.4593	.4580	.4853	.5525	.5268	.5207	.6274	.7108	.5984	.3758	.2221	.5467	.4729	.4800	.5430
R2:R3	.8642	.8924	.8241	.8546	.8930	.7748	.8855	.9181	.7883	.4366	.2172	.6853	.7442	.7444	.6351
V2:V4	.2744	.2310	.3473	.2608	.4602	.0286	.2464	.1907	.2739	-.1991	-.4028	.2100	.1469	.0482	.1394
V2:R4	.4434	.5701	.2914	.4763	.6435	.2102	.5239	.6376	.3059	-.3056	-.5237	.1667	.2165	.1506	.0606
R2:V4	.3292	.2383	.4868	.2797	.3521	.1163	.3050	.2553	.3414	-.2172	-.4504	.1946	.2131	.1571	.1548
R2:R4	.5896	.6102	.5812	.5732	.6873	.3096	.6503	.7404	.4482	-.3290	-.5721	.1586	.3104	.2749	.0938
V3:V4	.8489	.9174	.7670	.7943	.9153	.6823	.6241	.5400	.6921	.7587	.7527	.8682	.8372	.8453	.7912
V3:R4	.6930	.8551	.5249	.7571	.8216	.6766	.6074	.7209	.5100	.6629	.6166	.7766	.7815	.8651	.6571
R3:V4	.7018	.6149	.8163	.6631	.6806	.6323	.6265	.5882	.6700	.6992	.7186	.7841	.7722	.7601	.7771
R3:R4	.9163	.9018	.9394	.9147	.9403	.8399	.9284	.9411	.9022	.7051	.6760	.8268	.8651	.8462	.8269

(d)

COLUMN	FUKIAG			HOLVIL			TOTIBI			ANAIBI			YOROIZ		
VARIABLE	ORIGINAL	TREND	RESIDUE	ORIGINAL	TREND	RESIDUE	ORIGINAL	TREND	RESIDUE	ORIGINAL	TREND	RESIDUE	ORIGINAL	TREND	RESIDUE
N3:N4	.7754	.8146	.6568	.7349	.8387	.6442	.6275	.6078	.7203	.7239	.8143	.5983	.8491	.8887	.7864
N3:L4	.8535	.9076	.6491	.8648	.9257	.7770	.7134	.7534	.7483	.7664	.8096	.7213	.8991	.8988	.8562
L3:N4	.6644	.7043	.4867	.6432	.7687	.5293	.4703	.4112	.6152	.6815	.7988	.5070	.6785	.8406	.6539
L3:L4	.8025	.8490	.6200	.8276	.8986	.7181	.6063	.5722	.7460	.7532	.8150	.6816	.8018	.8762	.8114
N3:N5	-.3429	-.1473	-.6766	-.4550	-.3522	-.5563	-.5576	-.6149	-.4448	-.2971	-.1608	-.5632	-.4444	-.1081	-.5105
N3:L5	-.4850	-.3978	-.7102	-.6592	-.6938	-.6575	-.7321	-.7378	-.7369	-.3438	-.2259	-.5815	-.4510	-.1594	-.5535
L3:N5	-.3462	-.1825	-.6129	-.4889	-.4206	-.5944	-.8371	-.8714	-.7798	-.2843	-.1359	-.5585	-.6634	-.1474	-.5128
L3:L5	-.4902	-.4506	-.6138	-.6347	-.6708	-.6364	-.7640	-.8384	-.6466	-.3219	-.1976	-.5530	-.5785	-.1813	-.5754
N3:N6	.3976	.5677	-.0833	.3676	.5926	.1411	-.2582	-.3131	.0680	.5231	.6507	.3363	.3700	.6352	.4865
N3:L6	.5341	.6539	.1103	.4465	.6109	.2861	-.0681	-.0469	.1104	.5376	.6426	.3501	.3994	.6500	.4612
L3:N6	.3106	.4659	-.1520	.2686	.5003	.0208	-.5857	-.6306	-.3251	.4909	.6453	.2544	.0879	.5805	.3629
L3:L6	.4333	.5421	.0244	.3480	.5255	.1640	-.3347	-.3481	-.0737	.5153	.6477	.2871	.1294	.5939	.3265
N4:N5	.0949	.2714	-.1359	-.0882	.0184	-.1306	-.0654	-.0233	-.2955	.2478	.2954	.0291	-.0712	.2995	-.0872
N4:L5	-.0368	.0975	-.2588	-.1726	-.3147	-.0987	-.0876	-.0270	-.3051	.1933	.2428	-.0517	-.0321	.2572	-.1093
L4:N5	.1385	.2420	.0337	-.0860	-.0775	-.0682	-.1566	-.1513	-.3196	.3540	.4339	.1076	-.1214	.3221	-.0259
L4:L5	.0184	.0162	.0190	-.2167	-.3837	-.0724	-.1016	-.1393	-.1854	.3179	.3809	.0871	-.0510	.2864	-.0584
N4:N6	.8209	.9009	.5971	.8116	.8988	.7268	.3586	.3936	.4029	.9449	.9539	.9267	.7407	.9037	.8832
N4:L6	.8709	.9434	.6749	.8176	.8807	.7568	.5691	.6404	.5460	.8796	.9059	.8153	.7250	.8920	.7809
L4:N6	.7839	.8495	.6087	.7160	.8003	.6497	.2306	.2430	.2795	.9110	.9514	.8255	.6499	.8922	.8025
L4:L6	.8855	.9043	.7995	.8142	.8455	.8043	.5464	.5696	.6091	.9518	.9694	.8966	.6963	.9081	.8174
N5:N6	.6464	.6623	.7135	.5103	.4543	.5860	.9080	.9099	.7553	.5513	.5685	.4025	.6177	.6791	.3903
N5:L6	.4788	.5321	.5124	.3621	.3618	.4109	.6961	.7002	.4500	.5938	.6280	.4789	.5952	.6660	.4638
L5:N6	.4727	.4785	.5255	.2921	-.0113	.4951	.7225	.7928	.3719	.4932	.5182	.3084	.6033	.6335	.3496
L5:L6	.4096	.3898	.4972	.2946	.0724	.4409	.6843	.6810	.4924	.5642	.5846	.4486	.6103	.6359	.4236

Table 11. Correlation coefficient with the SEQNUM to examine the presence of the linear trend of change in time. Explanation of the SEQNUM is given in Table 3.

	FUKIAG	HOLVIL	TOTIBI	ANAIBI	YOROIZ
SEQNUM:X2	.3133	-.2776	-.1920	.3221	-.2769
SEQNUM:X3	-.2991	.0826	-.6682	-.2619	-.3921
SEQNUM:X4	-.3094	.1911	-.4608	-.2764	-.2443
SEQNUM:V2	.0611	-.1347	-.5371	.0919	-.5873
SEQNUM:V3	-.2755	.0961	-.4467	-.2344	-.3096
SEQNUM:V4	-.2605	.1515	-.1502	-.3299	-.2224
SEQNUM:N3	-.1517	.1688	-.5589	-.1719	-.0942
SEQNUM:N4	-.3547	.2183	-.3841	-.2947	-.0341
SEQNUM:N5	-.0589	.1042	.3735	-.1119	.4486
SEQNUM:N6	-.3056	.2496	.1882	-.2916	.2754

III.4.e. Correlation Under Limited Condition

The correlation coefficient changes its value when calculated only using the cases of certain condition. In this study the data are divided according to the thickness of sandstone or the sandstone ratio to examine the difference between the lithofacies (Table 12), that is, the difference between the characteristics of the sandstone in the alternation where the sandstone is dominant and that in the alternation where the shale is dominant.

In the distance series the correlation between the number of sandstone and the sandstone ratio is not significant when all cases are used, but it is positive when calculated for the cases with thin sandstone, although negative for the cases with thick sandstone. The correlation between the number and the thickness of sandstone is negative, but it is positive for the cases with thin sandstones.

In the thickness series, the positive correlation between the number and the

Table 12. Correlation coefficient under limited condition. LE: less than or equal, GT: greater than, ALL: no limitation although peculiar cases are excluded.

CONDITION	X2:X3	X2:X4	X3:X4	CONDITION	V2:V3	V2:V4	V3:V4
ALL	-.0955	-.3747	.4924	ALL	.5815	.1320	.6810
X3 LE .35	.6610	-.1854	.4433	V3 LE 100	.8092	.0649	.4948
X3 GT .35	-.5289	-.5795	.5823	V3 GT 100	.4445	-.2801	.5575
X4 LE 10	.5448	.3080	.4567	V4 LE 10	.8815	.4583	.6735
X4 GT 10	-.1568	-.6221	.5088	V4 GT 10	.6767	-.1222	.4846

CONDITION	N3:N4	N3:N5	N3:N6	N4:N5	N4:N6	N5:N6
ALL	.6972	-.3718	.1360	.0242	.6287	.7926
N3 LE 35	.2712	-.4044	-.3160	.4480	.5885	.9864
N3 GT 35	.7136	-.3447	.4938	.1812	.9339	.5216
N4 LE 10	.6191	-.4343	-.3726	-.0007	.0957	.9953
N4 GT 10	.5399	-.6260	-.0265	.0699	.7565	.7051

thickness of sandstone is more significant when calculated only for the cases with thin sandstones.

In the number series the correlation between the sandstone ratio and the thickness of graded bed is not significant when calculated for all the cases, but it is negative for cases with small values of the sandstone ratio, or positive for cases with large values.

The result suggests the necessity to calculate the correlation coefficient separately for the different types of sandstone, though there is another problem how to classify the sandstones into different types in the field.

III.5. Time Series Analysis

III.5.a. Purpose and Method

The time series analysis is to examine the pattern of change in time. There are many reports on the time series analysis in geology, for example, several papers of MERRIAM (1967). The analytical methods are refered in those of DAVIS (1973), MARUYAMA (1974) and MORITA (1955).

There are many reports on the method to extract the trend of change in the serial data in geology (ANDERSSEN and SENETA, 1971; ANDERSSEN *et al.*, 1970; WOOD and HOCKENS, 1970; JUPP, 1976). The most popular method, the running average method, is adopted in this study. The number of term and the treatment of the weight in the running average are determined by trial and error, and the methods were rejected when they cannot remove the random error, or they show the significant Slutsky-Yule effect (MORITA, 1955). Finally the 11-term weighted running average method is chosen, and the formula is:

$$y_i = \frac{1}{429} \cdot (-36 \cdot x_{i-5} + 9 \cdot x_{i-4} + 44 \cdot x_{i-3} + 69 \cdot x_{i-2} + 84 \cdot x_{i-1} + 89 \cdot x_i + 84 \cdot x_{i+1} + 69 \cdot x_{i+2} + 44 \cdot x_{i+3} + 9 \cdot x_{i+4} - 36 \cdot x_{i+5})$$

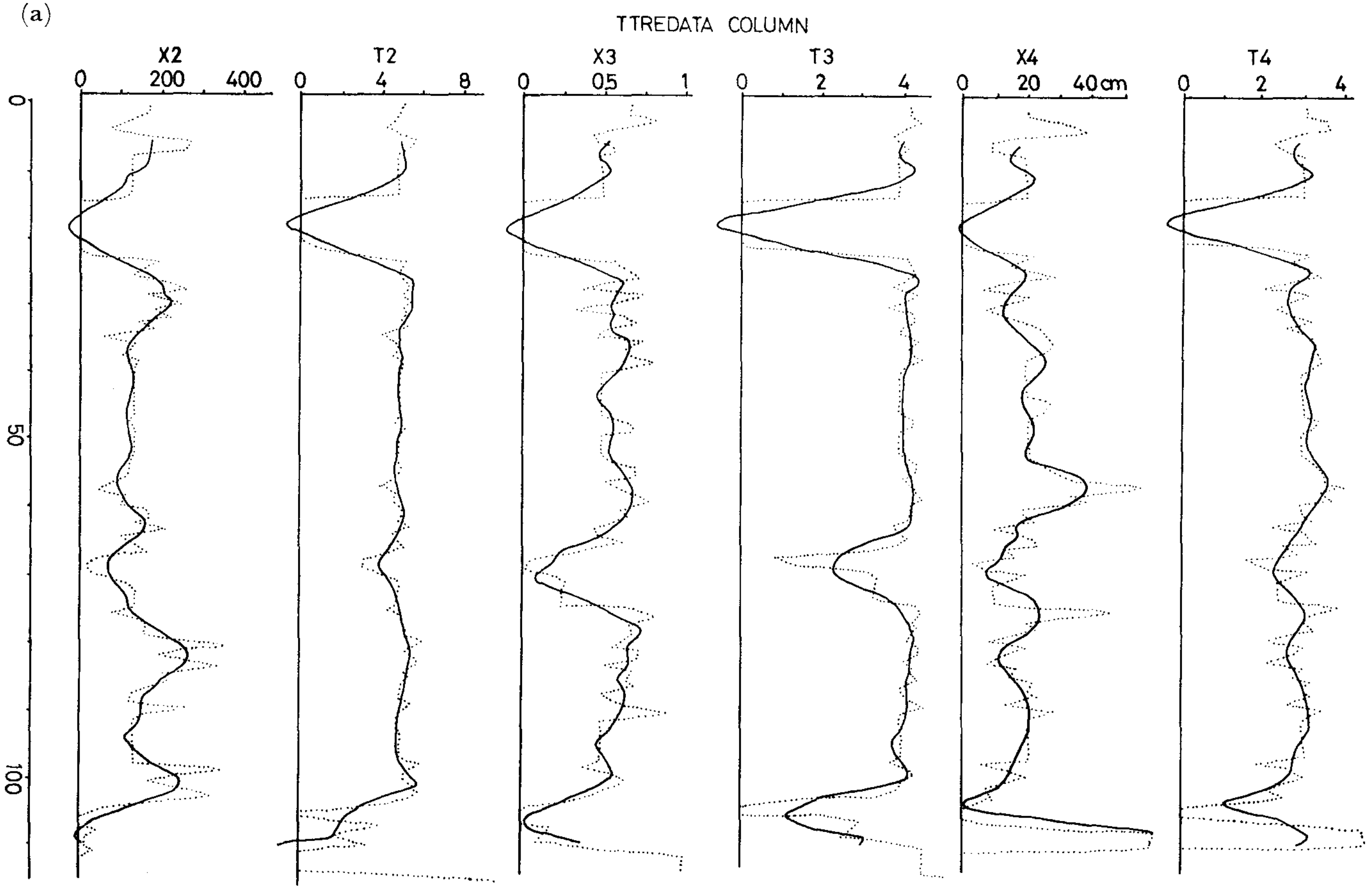
where x_i is observed value and y_i is averaged value.

In the result of the TTREDATA column (Figures 14a–c), the random errors are effectively removed. The resulted trend in the logarithmic scale intuitively seems to be more faithful to the general trend of change than that in the linear scale.

The fourier analysis is, by expanding in the fourier series, to decompose the original series into several fundamental periods. Many applications of the fourier analysis are reported in geology (ANDERSON and KOOPMANS, 1963; GEVIETZ, 1976). The result of the fourier analysis is generally summarized by plotting the power spectrum for each coefficient, and the power spectrum is considered to express the degree of the contribution of the period to the original series. The formulae of the fourier

Fig. 14. Result of the running average of the TTREDATA column. The dotted line shows the original data, and the solid one shows the 11-term running averaged data. (a) distance series, (b) thickness series, (c) number series.

(a)



(b)

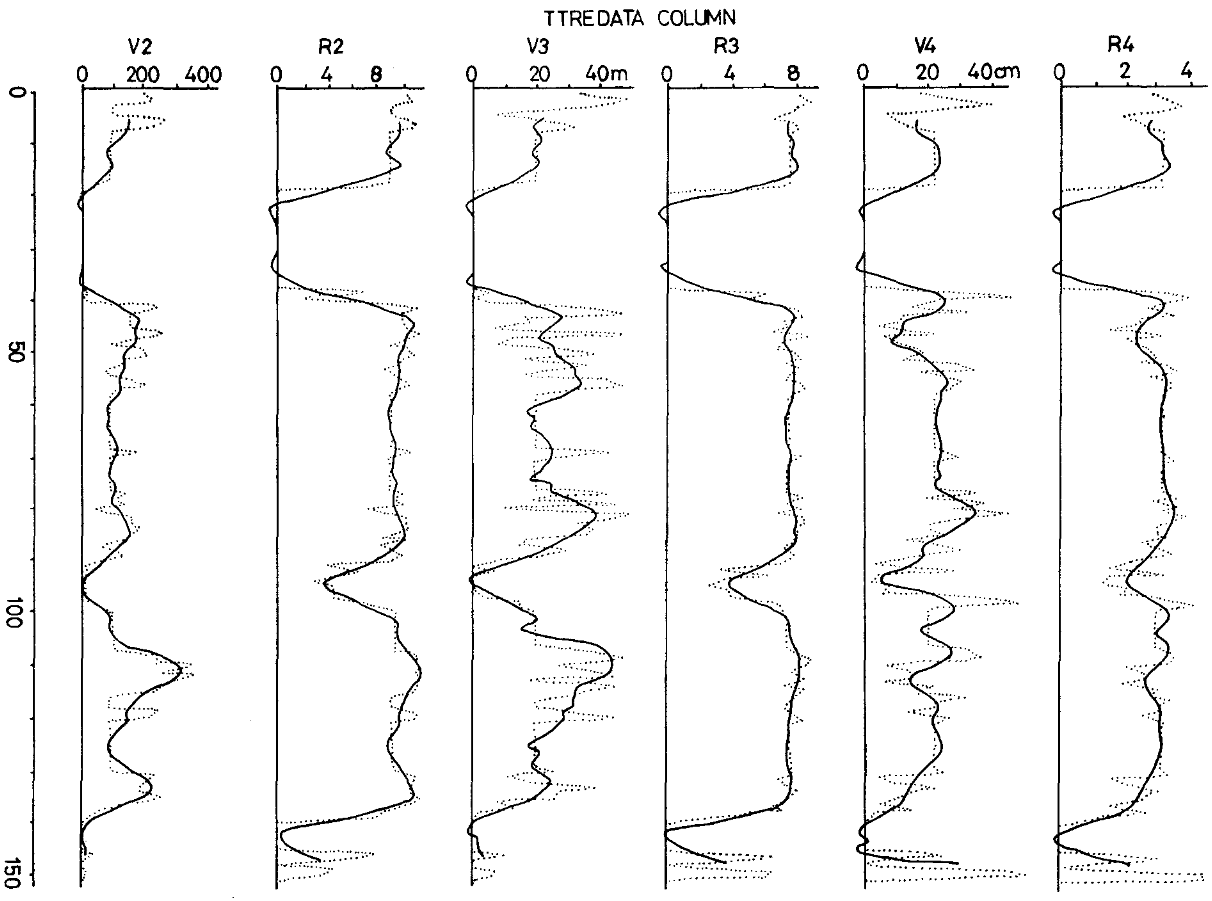
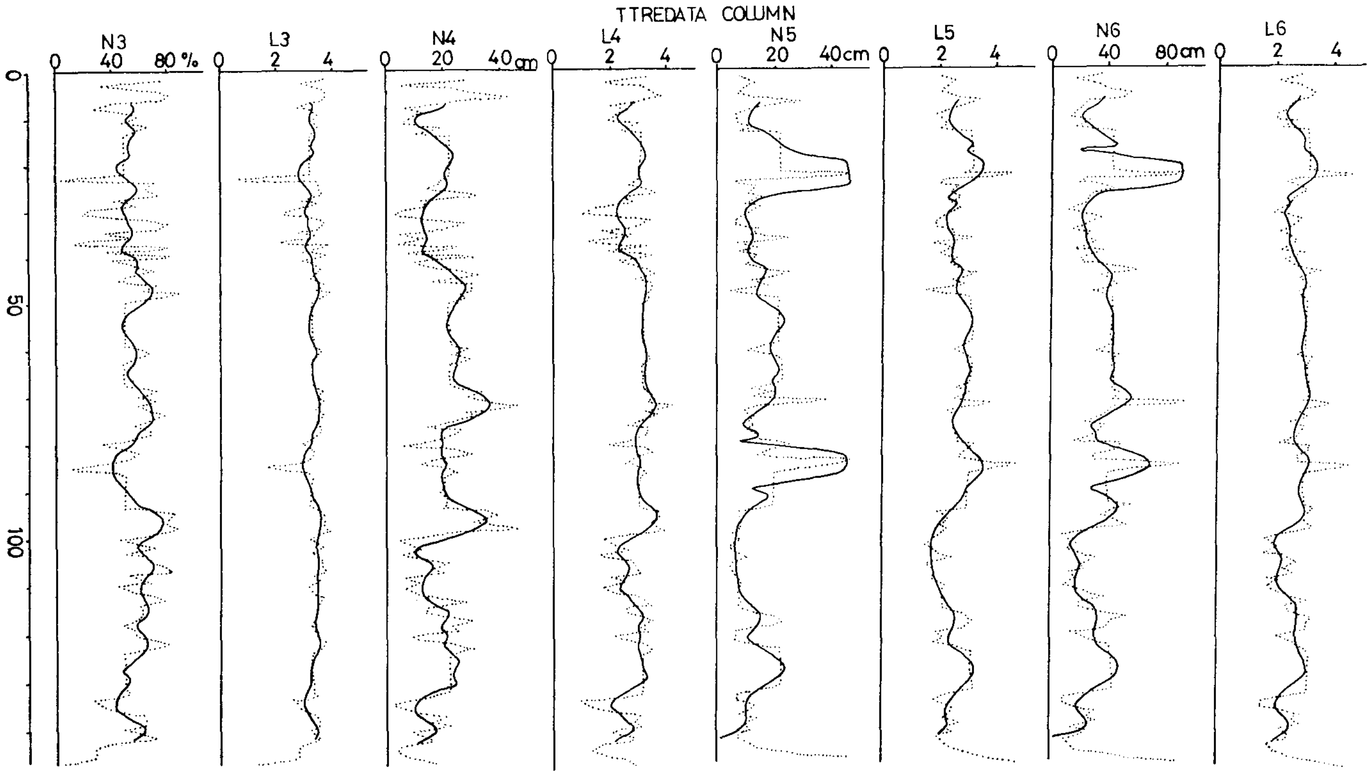

TTREDATA COLUMN
V2
0 200 400
R2
0 4 8
V3
0 20 40m
R3
0 4 8
V4
0 20 40cm
R4
0 2 4
0
50
100
150

Fig. 14. continued

(c)



series are:

$$Y_t = A_0 + \sum_{i=1}^{k} \left(A_i \cdot \cos \frac{2 \cdot \pi \cdot i \cdot t}{m} + B_i \cdot \sin \frac{2 \cdot \pi \cdot i \cdot t}{m} \right)$$

$$m = \begin{cases} n-1 & \text{when } n \text{ is odd number} \\ n-2 & \text{when } n \text{ is even number} \end{cases}$$

where n is the number of term, i is the degree of fourier series. Then the power spectrum S_i^2 is calculated:

$$S_1^2 = A_i^2 + B_i^2$$

The Schuster's test is adopted to examine the significance of the given peak of the power spectrum. It defines that the period is significant if:

$$S_i^2 \geqq \frac{4 \cdot s^2 \cdot c}{n}$$

is satisfied, where n is the number of term, s^2 is the variance of the original series, and c is constant for the significance level (MARUYAMA, 1974).

The result of the fourier analysis of the TTREDATA column is in Figure 15. The peaks of the power spectrum are different in each series and from each variable. It is worthy to note that some peaks in the linear scale are not significant in the logarithmic scale, and the reverse is also true.

The autocorrelation coefficient is adopted to analyze the series whose period of change varies in the series. The geologic serial data have such structure and this method is useful in geology (DUMITRIU and DUMITRIU, 1970). In actual analysis the correlogram is drawn by plotting the autocorrelation coefficients for the corresponding period, and the structure of the series is clarified from the pattern of the correlogram. The formulae of the autocorrelation coefficient A_j is:

$$A_j = \frac{\sum_{i=1}^{m} x_i \cdot x_{i+j} - \sum_{i=1}^{m} x_i \cdot \sum_{i=1}^{m} x_{i+j}}{\left\{ \sum_{i=1}^{m} x_i^2 - \frac{1}{m} \cdot \left(\sum_{i=1}^{m} x_i \right)^2 \right\} \cdot \left\{ \sum_{i=1}^{m} x_{i+j}^2 - \frac{1}{m} \cdot \left(\sum_{i=1}^{m} x_{i+j} \right)^2 \right\}}$$

where n is the number of term, and j is the lag of term for overlapping.

The result of the TTREDATA column is in Figure 16. The patterns are different in each series, and several variables have quite different patterns in the linear and the logarithmic scales.

The difficulty of this analysis is how to judge the patterns of the correlogram. For example it is not easy to determine whether the correlogram of **X4** is of the periodic series or of the random one.

Fig. 15. Plot of the power spectrum of the TTREDATA column. The dot shows that the period is significant at 0.10 level with the Schuster's test.

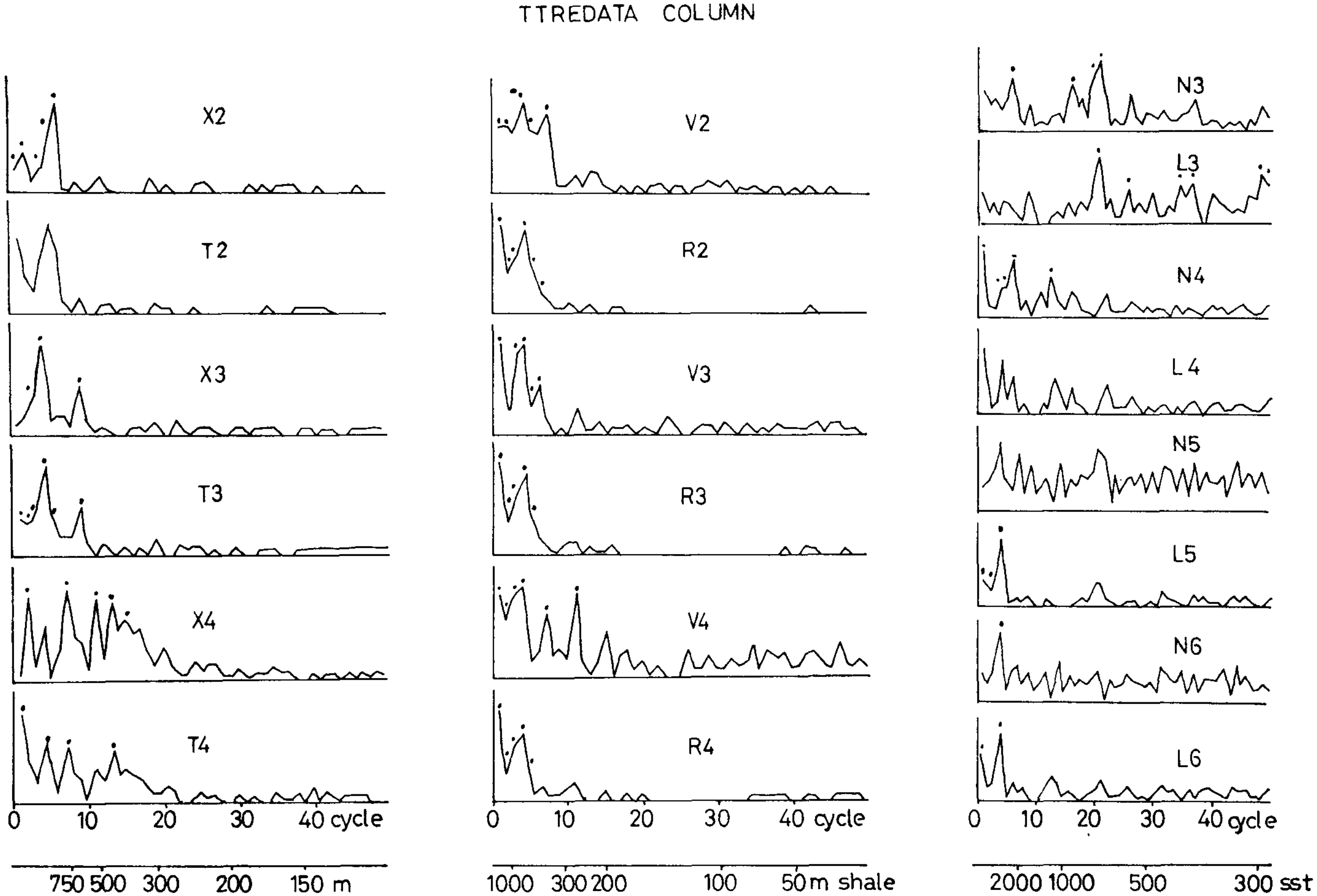
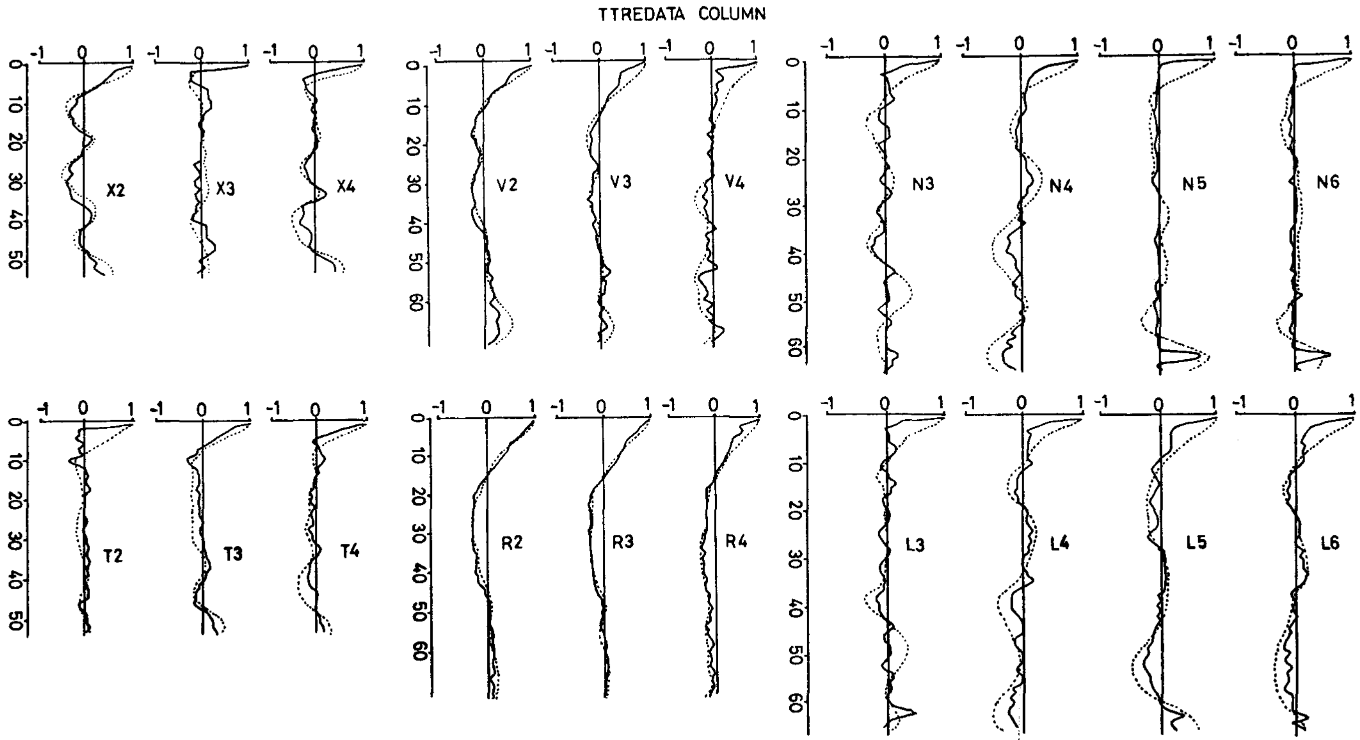


Fig. 16. Correlogram of the TTREDATA column. Attentions should be paid to the fact that the patterns of the same variable in the different series are not same, especially between those of the number of sandstone in the distance and thickness series.



III.5.b. Running Average

The results of the running average of each column were added to the display of the data in the system file which appeared in II.1.d. (Figures 12a–e). The followings are in common to all columns although only the trends in the linear scale are discussed.

In the distance series the trend of the number of sandstone is opposite to the trends of the sandstone ratio and the thickness of sandstone. In the thickness series the trends of the number, the total thickness and the mean thickness of sandstone resemble each other, although there are naturally some differences. In the number series the trends of the thickness of sandstone and that of shale are irrelevent to each other.

The characteristics of each column are as follows. The TOTIBI column has a significant trend in common to all series that the sandstones become thicker in the upper part of the column than in the lower. The ANAIBI column has only a small variation of the sandstone ratio in the number series when the random error was removed.

Other characteristics are mentioned in the discussion on the result of the correlation coefficient in III.4.d.

III.5.c. Fourier Analysis

The plot of resulted power spectrum of each column is in Figures 17a–c, and the followings are the characteristics of the patterns.

The TOTIBI and YOROIZ columns have a periodicity of long periods in the distance series and thickness series. The ANAIBI column shows fairly random pattern in the distance series and thickness series. The HOLVIL column has a definite periodicity in all series, especially of the sandstone ratio and the thickness of sandstone in the distance series.

The summary of the fourier analysis is listed in Tables 13a–c. In the view point of the assemblage of the significant periodicities, it is able to say that the periods are different in each series. For example, the period of the second degree of the sandstone ratio in the ANAIBI column is significant in the thickness series and number series in both of the linear and logarithmic scales, though it is not significant in the distance series.

For each column in the distance series and thickness series, there are fairly common periods between the sandstone ratio and the thickness of sandstone, and between the number of sandstone and the sandstone ratio. In the number series there are few periods in common between the thickness of sandstone and that of shale, excepting in the YOROIZ column.

Fig. 17. Plot of the power spectrum of each variable in each column. The meaning of dot is same with the Figure 15. (a) distance series, (b) thickness series, (c) number series.

(a)

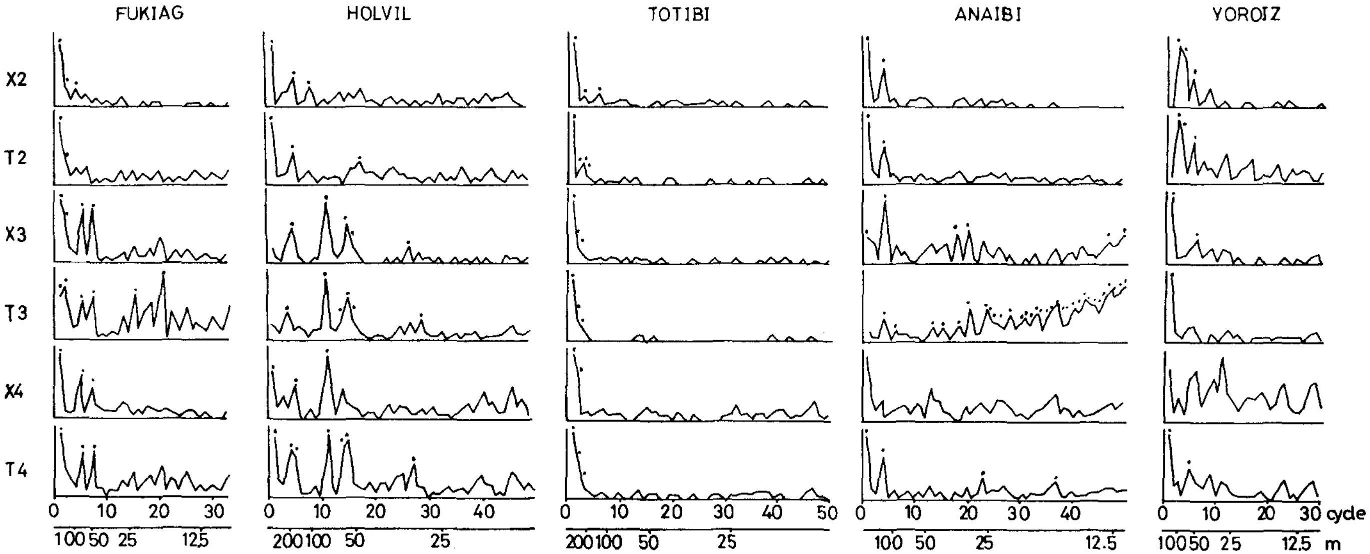
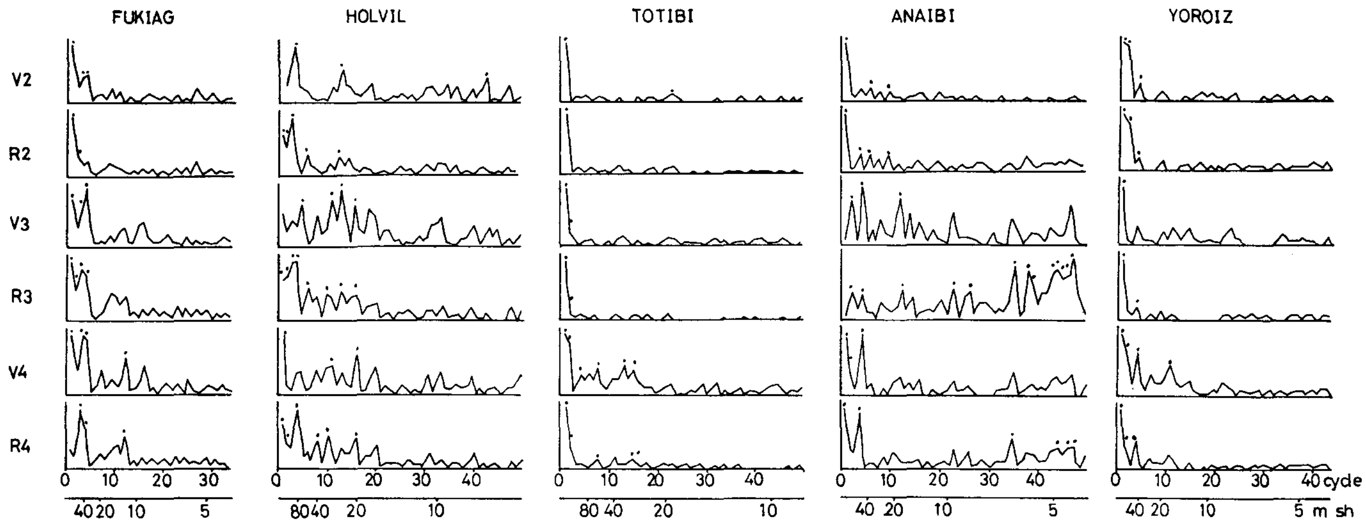
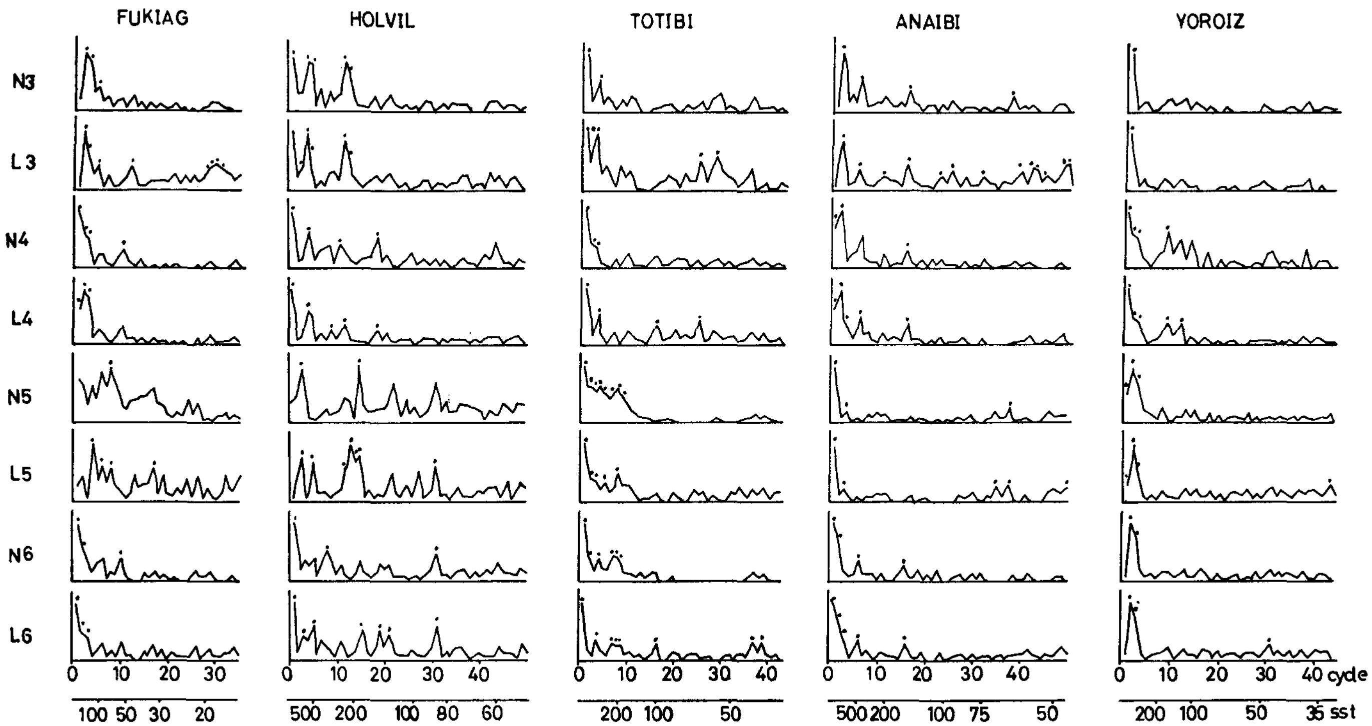


Fig. 17. continued

(b)



(c)



FUKIAG
HOLVIL
TOTIBI
ANAIBI
YOROIZ
N3
L 3
N4
L4
N5
L5
N6
L6
0 10 20 30
100 50 30 20
0 10 20 30 40
500 200 100 80 60
0 10 20 30 40
200 100 50
0 10 20 30 40
500 200 100 75 50
0 10 20 30 40 cycle
200 100 50 35 sst

Table 13. Summary of the fourier analysis. The symbol * shows that the period is significant at 0.10 level with the Schuster's test. (a) distance series, (b) thickness series, (c) number series.

(a)

	FUKIAG						HOLVIL						TOTIBI						ANAIBI						YOROIZ						
DEGREE OF	X	T	X	T	X	T	X	T	X	T	X	T	X	T	X	T	X	T	X	T	X	T	X	T	X	T	X	T	X	T	DEGREE OF
FOURIER	2	2	3	3	4	4	2	2	3	3	4	4	2	2	3	3	4	4	2	2	3	3	4	4	2	2	3	3	4	4	FOURIER
1	*	*		*	*	*	*	*			*	*	*	*	*	*	*	*	*	*	*			*	*	*	*	*		*	1
2	*	*	*	*										*	*	*	*	*							*	*					2
3	*		*										*	*	*	*		*													3
4										*		*		*					*	*	*	*		*	*	*		*			4
5			*	*	*	*	*	*	*		*	*																		*	5
6					*	*							*									*									6
7			*	*																											7
8							*																								8
9																															9
10									*	*	*	*																			10
11																															11
12																															12
13																															13
14										*		*																			14
15				*					*	*		*																			15
16									*	*																					16
17																															17
18																					*	*									18
19								*																							19
20				*																	*	*									20
	X	T	X	T	X	T	X	T	X	T	X	T	X	T	X	T	X	T	X	T	X	T	X	T	X	T	X	T	X	T	
	2	2	3	3	4	4	2	2	3	3	4	4	2	2	3	3	4	4	2	2	3	3	4	4	2	2	3	3	4	4	

(b)

	FUKIAG						HOLVIL						TOTIBI						ANAIBI						YOROIZ						
DEGREE OF	V	R	V	R	V	R	V	R	V	R	V	R	V	R	V	R	V	R	V	R	V	R	V	R	V	R	V	R	V	R	DEGREE OF
FOURIER	2	2	3	3	4	4	2	2	3	3	4	4	2	2	3	3	4	4	2	2	3	3	4	4	2	2	3	3	4	4	FOURIER
1	*	*	*	*	*			*		*	*	*	*	*	*	*	*	*	*	*			*	*			*	*	*	*	1
2		*		*				*		*		*			*	*	*	*			*	*	*		*	*			*	*	2
3	*		*	*	*	*	*	*		*															*	*					3
4	*		*	*	*	*				*		*							*	*	*	*	*	*					*	*	4
5									*		*														*	*					5
6								*		*									*	*							*				6
7																															7
8												*																			8
9																															9
10										*		*								*											10
11									*																				*		11
12					*	*															*	*									12
13							*	*	*	*							*	*					*								13
14																		*													14
15																	*						*								15
16										*	*	*																			16
17																															17
18																															18
19																															19
20																															20
	V	R	V	R	V	R	V	R	V	R	V	R	V	R	V	R	V	R	V	R	V	R	V	R	V	R	V	R	V	R	
	2	2	3	3	4	4	2	2	3	3	4	4	2	2	3	3	4	4	2	2	3	3	4	4	2	2	3	3	4	4	

(c)

DEGREE OF FOURIER	FUKIAG								HOLVIL								TOTIBI								ANAIBI								YOROIZ								DEGREE OF FOURIER
	N 3	L 3	N 4	L 4	N 5	L 5	N 6	L 6	N 3	L 3	N 4	L 4	N 5	L 5	N 6	L 6	N 3	L 3	N 4	L 4	N 5	L 5	N 6	L 6	N 3	L 3	N 4	L 4	N 5	L 5	N 6	L 6	N 3	L 3	N 4	L 4	N 5	L 5	N 6	L 6	
1			*	*			*	*	*	*	*	*			*	*	*	*	*	*	*	*	*	*			*	*	*	*	*	*	*	*	*	*	*	*			1
2	*	*	*	*			*	*										*	*		*	*	*		*	*	*	*			*	*			*	*	*	*	*	*	2
3	*	*	*	*				*		*			*	*		*	*	*	*	*	*	*						*	*	*		*			*	*	*	*	*	*	3
4						*			*	*	*	*									*		*	*																	4
5	*	*							*	*		*		*		*					*	*																			5
6						*																			*	*	*	*			*	*									6
7																					*		*	*																	7
8					*	*									*						*	*	*	*																	8
9												*									*		*	*											*	*					9
10			*				*																																		10
11											*																														11
12		*							*	*		*		*																						*					12
13									*	*				*																											13
14														*																											14
15													*	*		*																									15
16																				*				*	*	*	*	*			*	*									16
17						*																																			17
18																																									18
19											*	*				*																									19
20																																									20
	N 3	L 3	N 4	L 4	N 5	L 5	N 6	L 6	N 3	L 3	N 4	L 4	N 5	L 5	N 6	L 6	N 3	L 3	N 4	L 4	N 5	L 5	N 6	L 6	N 3	L 3	N 4	L 4	N 5	L 5	N 6	L 6	N 3	L 3	N 4	L 4	N 5	L 5	N 6	L 6	

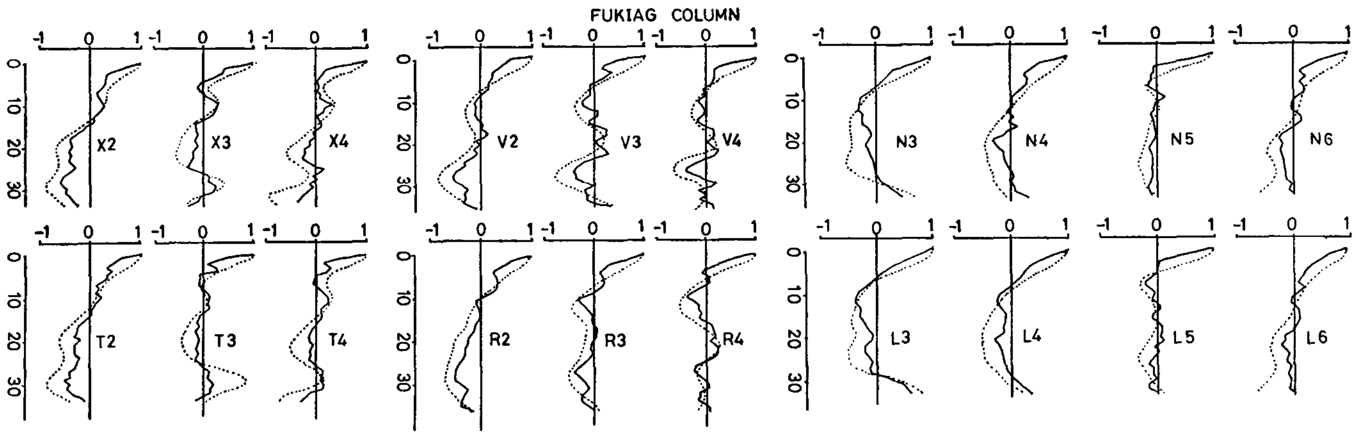
III.5.d. Autocorrelation Analysis

The resulted correlograms of each column are shown in Figures 18a–e, and the judged patterns of the correlograms are summarized in Tables 14a–c. The important points of the result are that the same variable has a different pattern in each series, and that the same variable shows the similar patterns in both of the linear and logarithmic scales. The example of the former is the correlogram of the sandstone ratio in the HOLVIL column that shows the definite periodic pattern in the distance series and number series, although it shows the random pattern in the thickness series. The examples of the latter are the correlograms in the FUKIAG column in the distance series and number series, and those of the sandstone ratio of the HOLVIL column in all the series.

The patterns of correlogram of each variable are as follows. In the distance series the pattern of the number of sandstone do not resemble those of the sandstone ratio and the thickness of sandstone. In the thickness series the patterns of the number of sandstone, the total thickness and the mean thickness of sandstone resemble each other. In the number series the pattern of the thickness of shale is quite different from that of the other variables.

Fig. 18. Correlogram of each variable in each column. The dotted line shows the correlogram of the running averaged data, and the solid one shows that of the original data. (a) FUKIAG column, (b) HOLVIL column, (c) TOTIBI column, (d) ANAIBI column, (e) YOROIZ column.

(a)



(b)

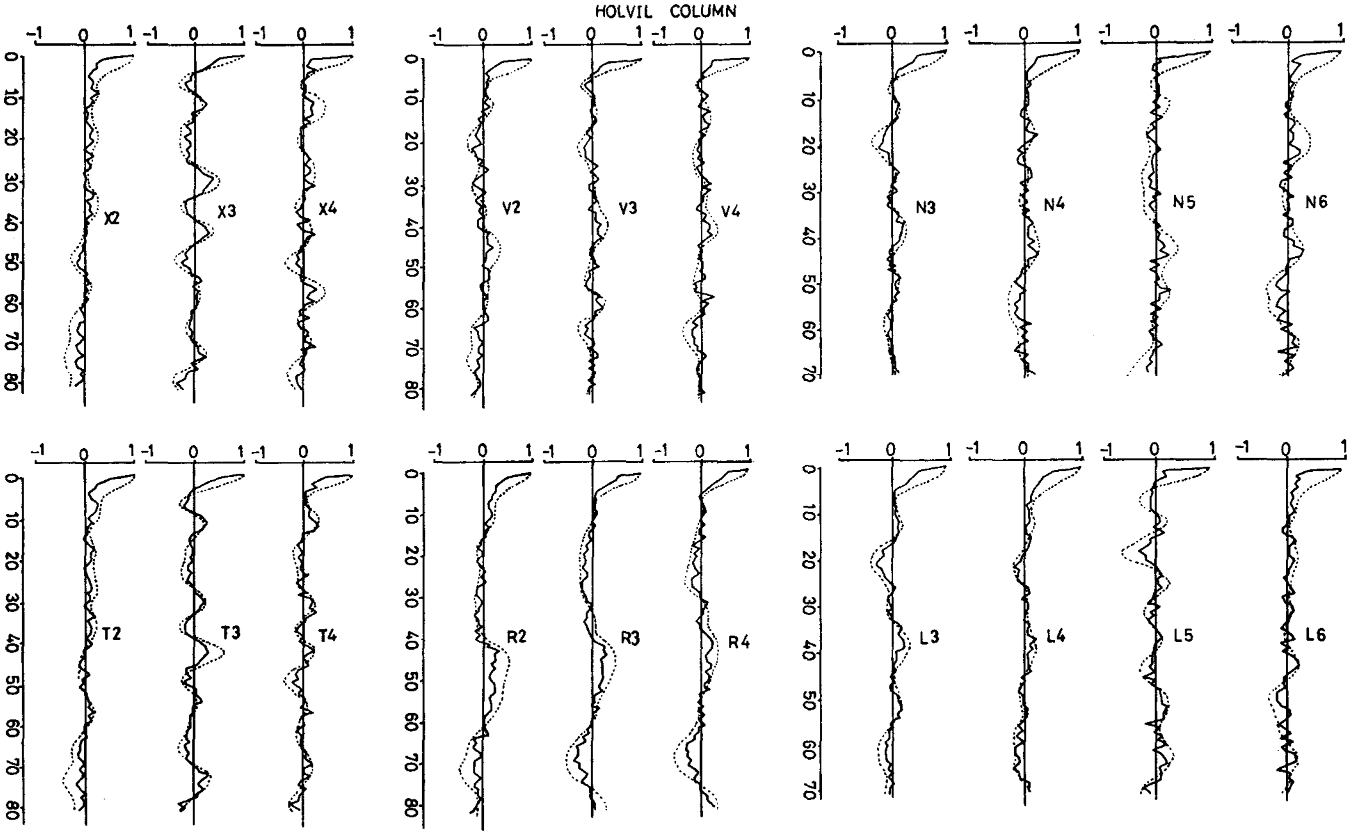
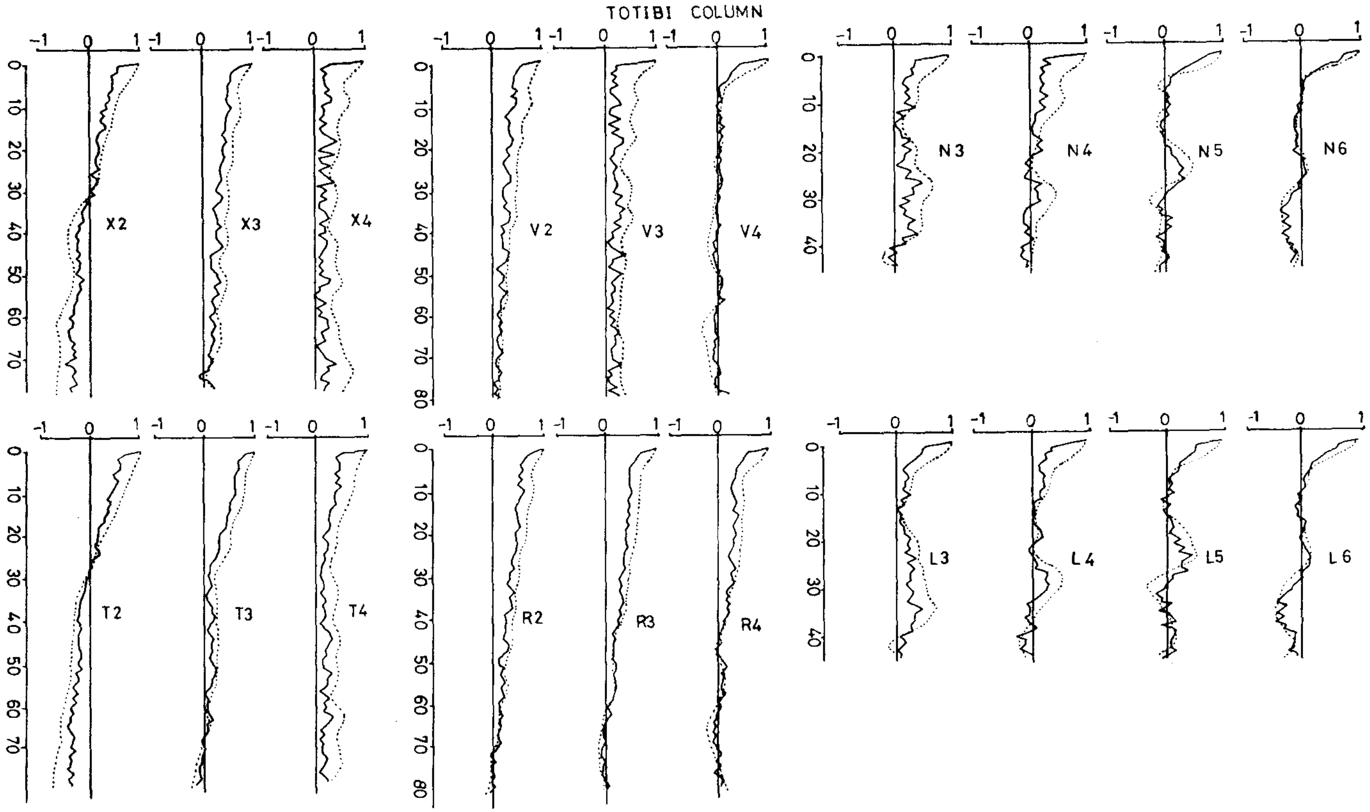

HOLVIL COLUMN
X2
X3
X4
V2
V3
V4
N3
N4
N5
N6
T2
T3
T4
R2
R3
R4
L3
L4
L5
L6

Fig. 18. continud

(c)



(d)

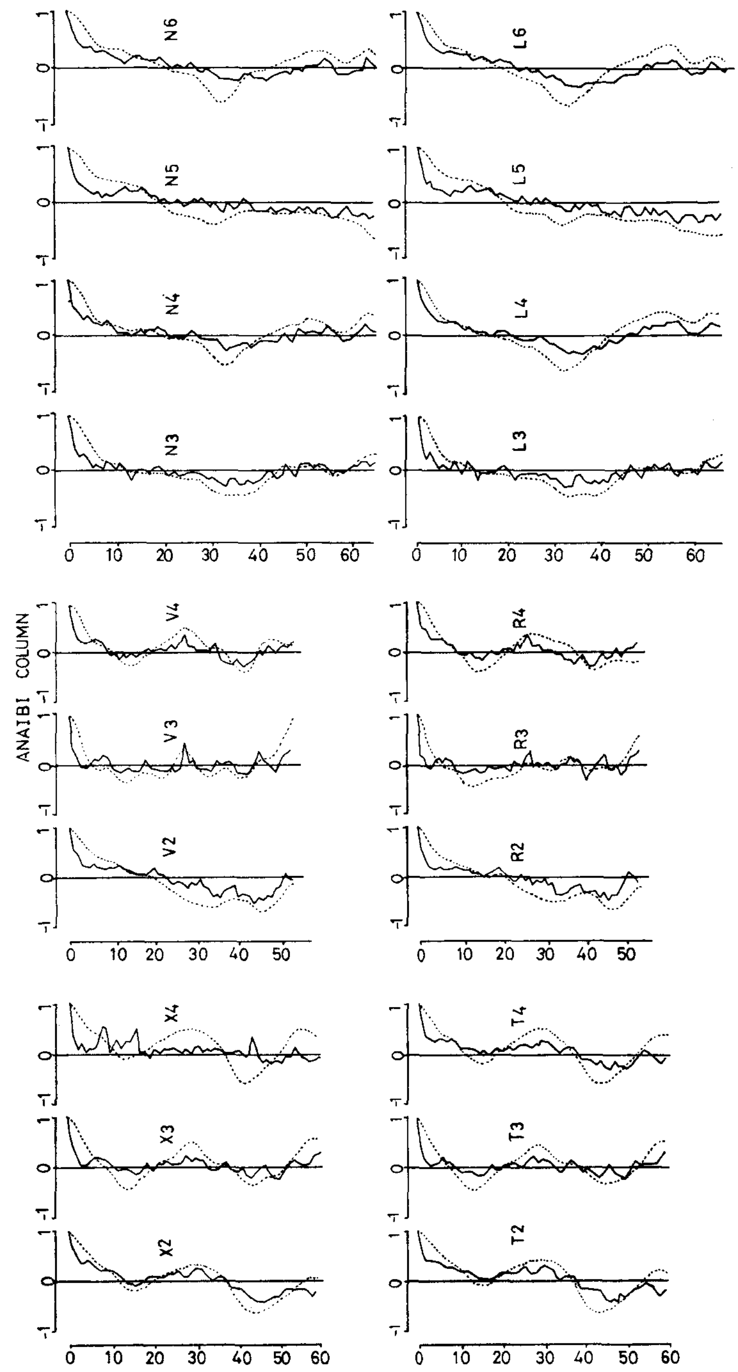

ANAIBI COLUMN
N3
N4
N5
N6
L3
L4
L5
L6
V2
V3
V4
R2
R3
R4
X2
X3
X4
T2
T3
T4

Fig. 18. continued

(e)

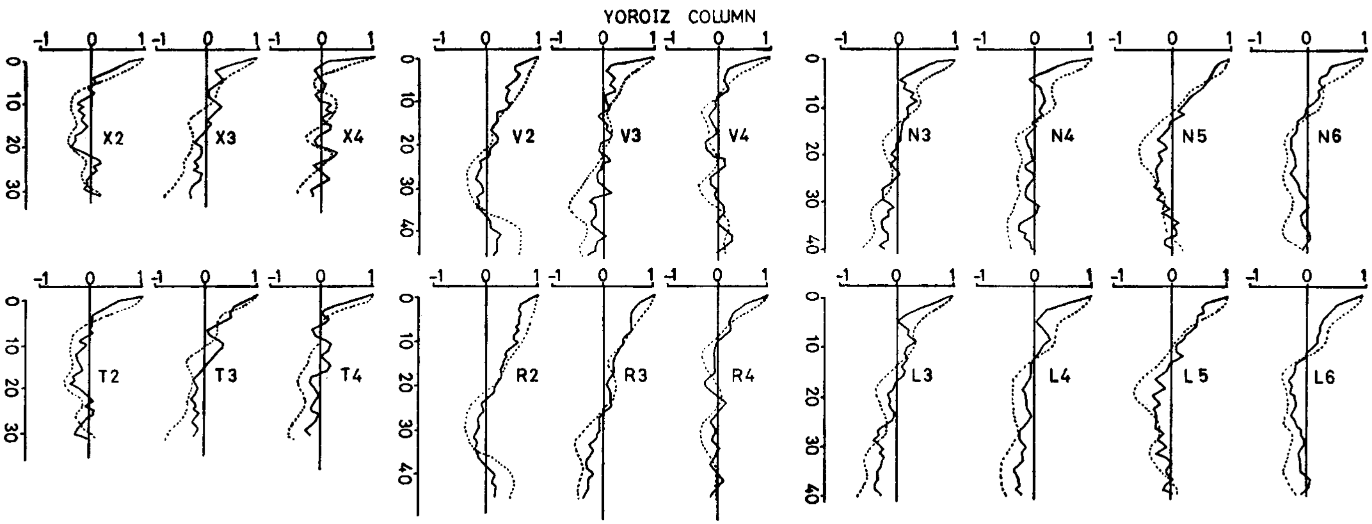


Table 14. Summary of the autocorrelation analysis. The upper one in the block is the pattern judged on the correlogram in the linear scale, and the lower in the logarithmic scale. (a) distance series, (b) thickness series, (c) number series.

(a)

COLUMN		X2/T2	X3/T3	X4/T4
FUKIAG	X	$T_{60}+R_5$	$C_{10}+R$	$T_{60}+C_{10}+R$
	T	$T_{60}+R$	R	$C_{10}+R$
HOLVIL	X	$T_{200}+R$	$C_{11}+R$	$C_{10}+R$
	T	$T_{200}+R$	$C_{11}+R$	$C_{11}+R$
TOTIBI	X	$T_{150}+R$	$L+R_{11}$	$L+R_{11}$
	T	$T_{120}+R$	$T_{200}+R_{11}$	$L+R_{11}$
ANAIBI	X	$T_{120}+C_{31}+R_6$	R_{10}	$C_{30}+R_{10}$
	T	$T_{120}+C_{30}+R$	R_8	$T_{150}+C_{29}+R_9$
YOROIZ	X	$T_{40}+R_7$	$T_{80}+R_7$	$C_{11}+R_6$
	T	$T_{40}+R_7$	$T_{80}+R_7$	$T_{60}+R_8$

(b)

COLUMN		V2/R2	V3/R3	V4/R4
FUKIAG	V	$T_{60}+C_{19}+R$	$C_{20}+R_5$	$C_{21}+R_6$
	R	$T_{60}+R$	$T_{50}+C_{18}+R_6$	$C_{21}+R_6$
HOLVIL	V	R	R	R
	R	$C_{46}+R$	$C_{45}+R$	$C_{43}+R$
TOTIBI	V	$L+R_{10}$	$L+R_{10}$	R
	R	$T_{300}+R_{10}$	$T_{300}+R_8$	$T_{200}+R_{10}$
ANAIBI	V	$T_{100}+R_{10}$	C_9+R	$C_{27}+R_{10}$
	R	$T_{100}+R_{10}$	R_6	$C_{27}+R_{10}$
YOROIZ	V	$T_{60}+R_8$	$T_{70}+R_7$	$T_{50}+R_7$
	R	$T_{60}+R$	$T_{100}+R_6$	$T_{60}+R_7$

L: linear trend
T_n: n-term cyclicity which is longer than half of column
C_n: n-term cyclicity which is shorter than half of column
R_n: random but similar with n-term cyclicity
R: random without cyclicity longer than 5-term

Table 14. continued

(c)

COLUMN		N3/L3	N4/L4	N5/L5	N6/L6
FUKIAG	N	$C_{32}+C_{17}+R$	$C_{36}+C_5+R$	R	$T_{60}+C_{13}+R$
	L	$C_{30}+C_6+R$	$C_{38}+C_{15}+R$	R_5	$T_{60}+C_8+R$
HOLVIL	N	$C_{12}+R$	R_5	R	R
	L	$C_{13}+R$	R	$C_{12}+R$	R
TOTIBI	N	$T_{200}+C_9+R_4$	$T_{200}+R$	$C_{12}+R$	$C_{24}+R$
	L	$T_{200}+R_4$	$T_{200}+R$	$C_{24}+R$	$C_{24}+R$
ANAIBI	N	$T_{70}+R$	$T_{66}+R$	$T_{150}+R$	$T_{64}+R$
	L	$T_{70}+R$	$T_{64}+R$	$T_{150}+R$	$T_{64}+R$
YOROIZ	N	$T_{80}+R$	$T_{80}+R$	$T_{50}+R$	$T_{60}+C_{10}+R$
	L	$T_{80}+C_9+R$	$T_{80}+C_8+R$	$T_{50}+R$	$T_{60}+C_{10}+R$

L: linear trend
T_n: n-term cyclicity which is longer than half of column
C_n: n-term cyclicity which is shorter than half of column
R_n: random but similar with n-term cyclicity
R: random without cyclicity longer than 5-term

IV. Discussion

The geologic columns of the Izumi Group were transformed into three different series based on the three sedimentation models. This process has two meanings.

First it becomes possible to make the statistical analysis of the geologic column data through the quantification of the qualitative data, the balancing of the distribution of the data, and the control of the number of cases into the preferable one for the analysis. Second and geologically more important, the process enables us to treat the geologic column as a time series in a strict sense. That is, the relation among the geologic events could be examined by adding the time scale of their occurrence more accurately.

Of course this process has many problems which are usually formed in the data analysis. Is the accuracy of the data sufficient for the purpose of the analysis? Is the quality of the data proper for the analysis? How to treat the missing values and discontinuity of the data? And so on. The most essential problem is, however, the choice of the series into which the original geologic column is transformed.

The result of the analysis of the Izumi Group is summarized in the followings (Table 15).

Table 15. Relations between the number and thickness of sandstone, and between the thickness of sandstone and that of shale, summarized for the five columns of the Izumi Group.

MODEL	CONSTANT DEPOSITION MODEL	MIXED DEPOSITION MODEL	PERIODIC DEPOSITION MODEL
SERIES	DISTANCE SERIES	THICKNESS SERIES	NUMBER SERIES
PAIR OF VARIABLE	NUMBER OF SANDSTONE : THICKNESS OF SANDSTONE	NUMBER OF SANDSTONE : THICKNESS OF SANDSTONE	THICKNESS OF SANDSTONE : THICKNESS OF SHALE
FUKIAG	-	+	0
HOLVİL	-	+	-*
TOTIBI	/	/	/
ANAIBI	-	-	+
YOROIZ	-	+	0

+: same pattern, -: opposite pattern, 0: independent, /: not considered,
*: only in the logarithmic scale.

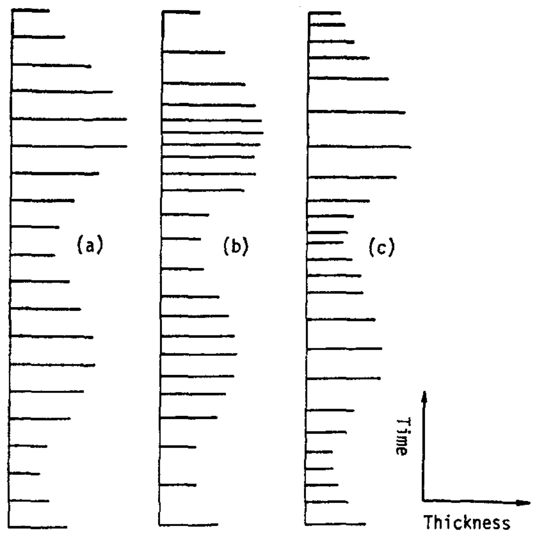


Fig. 19. Diagrams showing the relation between the number and thickness of sandstone. A pillar corresponds to a sandstone layer and its length shows the thickness of sandstone. (a) independent, (b) same pattern, (c) opposite pattern.

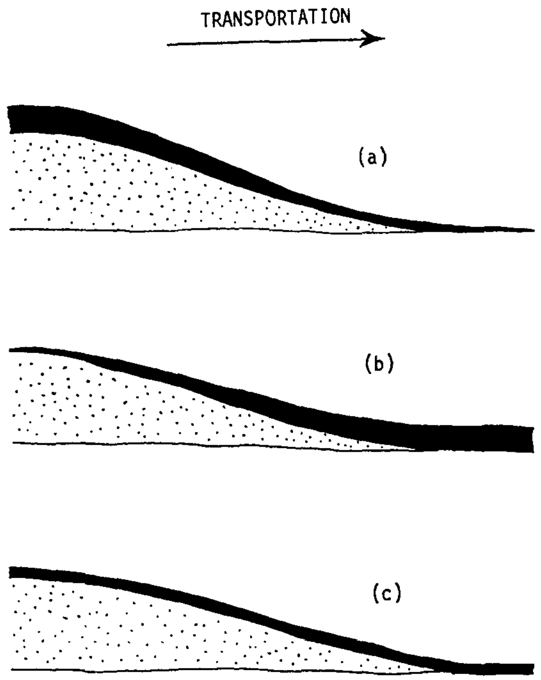


Fig. 20. Diagram showing the relation between the thickness of sandstone and that of shale. (a) same pattern, (b) opposite pattern, (c) independent.

Five columns are processed, but the TOTIBI column is omitted from the discussion because it cannot be analyzed satisfactorily, because there is found a strong linear trend of change. The constant deposition model should be rejected for the other four columns, because there is an inconsistency in the distance series that the number and the thickness of sandstone show the opposite pattern of change (Figures 19a–c). For the ANAIBI column the periodic deposition model is considered to be suitable, because the number and the thickness of sandstone show the opposite pattern of change in the thickness series, and because the thickness of sandstone and that of shale show the same pattern in the number series. For the FUKIAG, HOLVIL and YOROIZ columns the mixed deposition model is considered to be consistent, because the number and the thickness of sandstone show the same pattern of change in the thickness series. But for the HOLVIL column the periodic deposition model cannot be rejected since the thickness of sandstone and that of shale show the opposite pattern of change in the logarithmic scale in the number series (Figures 20a–c).

In the precedings the suitable model for each column is decided based on the

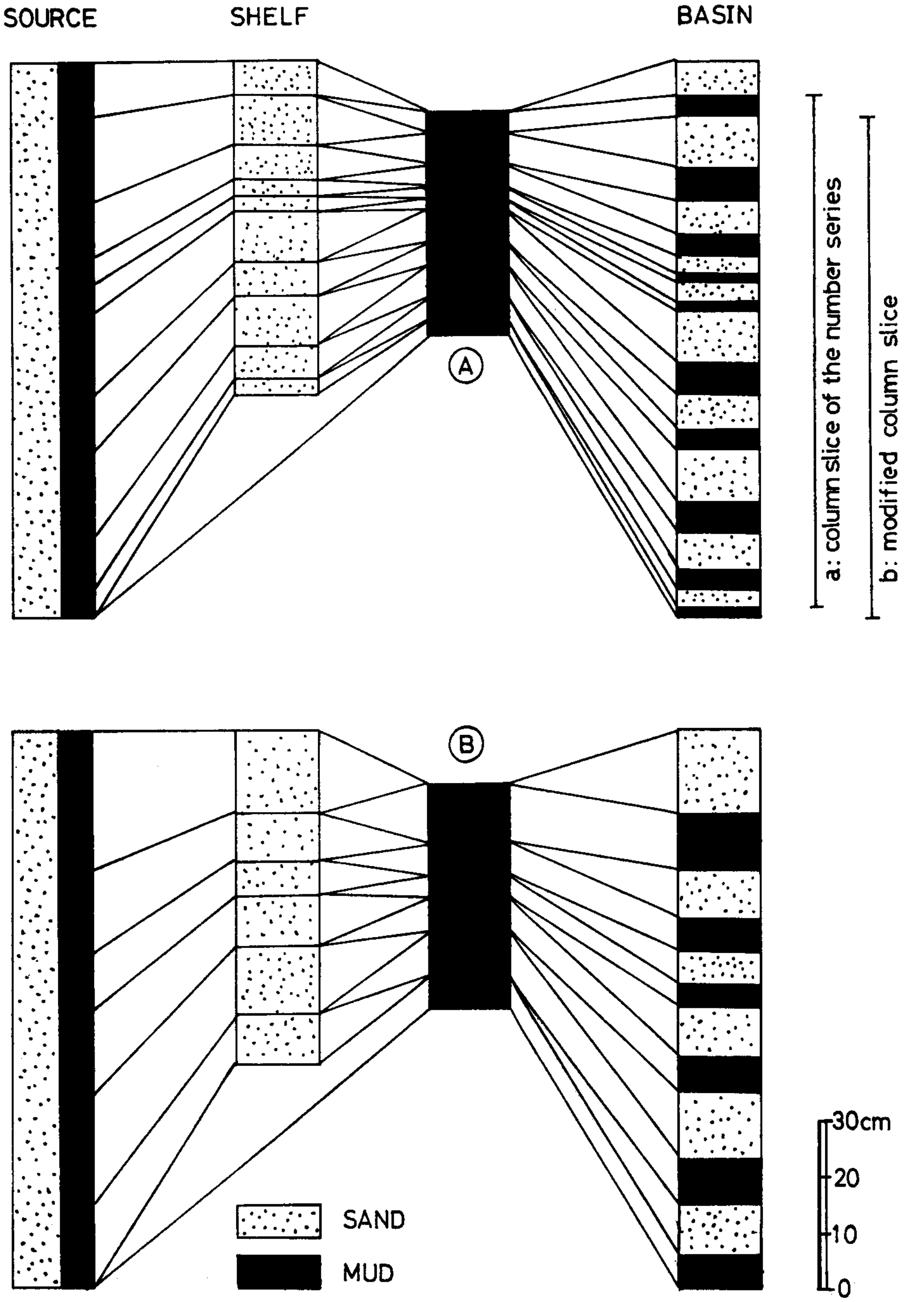


Fig. 21. Imaginary columns explaining why the mixed deposition model is rejected and the periodic deposition model is accepted for the ANAIBI column. The mud is directly transported into the basin by suspension. On the other hand the sand is primarily deposited on the shelf, and is secondarily transported into the basin by turbidity current.

relations between the number and the thickness of sandstone and between the thickness of sandstone and that of shale. But the sedimentation theory on these relations should be established in the future by collecting and synthesizing the data in the field, recent ocean and hydrologic laboratory. So it should be noted that the following discussion has a limitation that the judgement of the model is a temporary one.

Based on the informations in the field the mixed deposition model is accepted and the periodic deposition model is rejected for the Izumi Group. But based on the statistical analysis the former is accepted for three columns and the latter for two columns, and for the HOLVIL column both models are accepted. The difference between the two models are whether the mud was transported by the suspension or by turbidity currents, but practically it comes to the problem which type of transportation played more important role. So it is possilbe that the both models are accepted for a column, and it is one of the limitation of this analysis.

For the ANAIBI column the periodic deposition model is accepted, but the top of the sandstone layer in this column is also too sharp to regard a pair of sandstone and shale as a graded unit. This column has characteristics as follows. (1) The variance of the sandstone ratio is small. (2) The shale is thin and the variance of the thickness is small. (3) The sandstones are almost 10 to 20 cm thick and there are few thicker sandstones.

These characteristics suggest that the erosion in the hinterland was processed at a stable rate, and that the turbidity currents were generated so frequently that the ratio of the sand transported by turbidity currents to the mud transported by suspension became constant in the basin.

As indicated by the first characteristic, the sandstone ratio is considered to be constant for all column slices in the thickness series. Then the total thickness of sandstone is also constant, and so the number of sandstone is in inverse proportion to the thickness of sandstone (Table 16a, Figure 21).

The sandstone ratio is constant for all the modified column slices (Figure 21b) which are defined from the base of shale to the top of sandstone. The column slice

Table 16. Statistics of the explanation column in Figure 21. (a) thickness series, (b) number series.

(a)

COLUMN SLICE	V2 (beds)	V3 (cm)	V4 (cm)
A	10	60	6
B	6	60	10

(b)

COLUMN SLICE	N3 (%)	N4 (cm)	N5 (cm)	N6 (cm)
a	58.7	6.0	4.2	10.2
b	60.0	6.0	4.0	10.0

in the number series (Figure 21a) is not same with the modified column slice (Figure 21b), but they resemble to each other, because of the second characteristic. So the thickness of sandstone and that of shale in the number series show a positive correlation (Table 16b).

This interpretation is basically of the mixed deposition model, but it can be regarded as a modified periodic deposition model on the other hand.

Because only a small part has been analyzed with this method, it is not certain whether such explanation is possible or impossible for the whole Izumi Group. Especially the muddy facies in the central part of the basin, which is described in the map of SUYARI (1973), should be treated.

Furthermore other models should be considered which include the models not only for the geologic column data but also for the panel diagram and the block diagram data, that is, those interpreting the change of two or three dimensions. And the stochastic elements should be included in the future models.

The conquest of the general problem in the data analysis should improve the sedimentation model which will clarify the sedimentation mechanism and contribute to the construction of the geologic history.

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Maruyama	丸 山	Minato	湊
Sennan	泉 南	Shichi	志 知
Tozaki	門 崎	Tsui	津 井
Yoroizaki	鎧 崎		